DOCTORAL PROGRAM
ON OCCUPATIONAL
SAFETY AND HEALTH

A thesis submitted for the degree of
Philosophiae Doctor (Ph.D.) in Occupational Safety and Health

INFLUENCE OF SEVERE COLD THERMAL ENVIRONMENT ON CORE AND SKIN TEMPERATURES

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2017

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ACKNOWLEDGMENTS

The thesis is a result of many experiences I have encountered during the past three years of my doctoral research. The research activities were influenced and developed by many remarkable individuals whom therefore I wish to acknowledge.

First and foremost I wish to thank my first supervisor, Professor João Santos Baptista, director of the master course of Occupational Safety and Health at the Faculty of Engineering. He has been supportive since the days I arrived to Porto and began with my work, always found time for me, spreading positive energy all around my ideas and my worst challenges.

Many thanks to my second and third supervisors, Professor José Torres Costa and Professor Mário Vaz, for their revisions, suggestions and improvements of the research.

I wish to thank Professor Beda Barkokebas and Professor Laura Martins, which as my doctoral mobility supervisors had special contributions while conducting the industrial research in Brazil.

I wish to express special thanks to Professor Joana Guedes for all her help on using equipment and analysing the data; Professor Margarida Brito for all her assistance in statistical data analysis; and professor Olivia Pinho for her assistance during the organization of the 1st Doctoral Congress in Engineering held in FEUP in 2015.

I want to thank Prof. Luiz Bueno da Silva, Prof. Hélio Cavalcanti, Prof. Teerayut Sa-ngiamsak (Mark), Felipe Mendes, Ana Freitas, Ana Castro Paiva, Carla J. Rocha, Raquel Martins and Célia Ferreira, for their assistance and prompt help whenever it was needed.

During the last months of laboratory research activities I had a pleasure to meet and tutor master students João Cardoso and Joaquim Oliveira, which I thank for their diligent work.

The industrial research project was financially supported by the European Commission, Erasmus Mundus "BE Mundus" international project during the year 2015/2016. Many thanks for all the support from the Federal University of Pernambuco (UFPE) and the University of Pernambuco (UPE). Special thanks to the Laboratory of Safety and Occupational Hygiene (LSHT) of the UPE, which contributed greatly for this project to be successfully conducted.

The biggest thanks of all go to all the volunteers which participated in industrial and laboratory research activities.

And last, but definitely not least, I wish to thank my family and friends who gave me all the strength, support and motivation in order to accomplish all the achievements during the past years.

In Porto, Januray 2017 Tomi Zlatar

ABSTRACT

Exposure to severe cold thermal environment (SCE) is a significant risk factor present indoor in all seasons (in the frozen food industry) and outdoor during the winter season (in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work, among winter sport athletic disciplines and related occupations). The aim of this thesis was to study the influence of severe cold thermal environment on core and skin temperature variations and its recovery period. By using the general lifestyle questionnaire, thermal sensation questionnaire, cold work health questionnaire, blood pressure and heart rate equipment, thermometer telemetry capsule for measuring the intra-abdominal temperature and 8 skin temperature sensors, a study was conducted in laboratory and in a frozen food processing industry. In total, 39 subjects participated in the trials: 27 acclimatized workers (13 male and 14 female) from the industrial research; and on 12 non-acclimatized volunteers from the laboratory research. The findings show that the mean skin temperature decreases when exposed to SCE, while highest decrease and fluctuations as fastest recovery was found in hands and forehead. While previous studies measuring rectal and tympanum temperature generally found a decrease in core temperature, the results could be biased due to a non adequate measuring method and type of activity conducted by subjects (rectal temperature increased only in studies where subjects used more legs). Studies conducted as part of this thesis, measuring intra-abdominal core temperature, show increase/decrease in core temperature during work in SCE depending on physical exertion, with recovery already during exposure to SCE. Increase in core temperature was co-related with vasoconstriction and higher heat production as a result from higher physical exertion. Further studies should be conducted in SCE measuring core temperature through oesophageal or intra-abdominal temperature, and measuring skin temperature in more points (adding points in the extremities as face, fingers and toes).

Keywords: cold exposure, thermoregulation, frozen food industry, cold store, thermal sensation

RESUMO

A exposição ao Ambiente Térmico Extremo Frio (ATEF) é um fator de risco significativo presente em todas as estações do ano (na indústria de alimentos congelados) e ao ar livre durante o inverno (em ocupações como marinha, exército, agricultura, silvicultura, Construção, desporto de Inverno e profissões afins). O objetivo desta tese foi o de estudar a influência do ATEF sobre a temperatura interna e a temperatura da pele. Foi usando um questionário de estilo de vida geral, um questionário de sensação térmica, um questionário de saúde do trabalho em ambiente frio. Foram ainda medidos os seguintes parâmetros: pressão arterial, frequência cardíaca, temperatura intra-abdominal e temperatura da pele em 8 pontos. A recolha de dados decorreu em ambiente industrial e em laboratório. No total, participaram 39 indivíduos nos ensaios: 27 trabalhadores aclimatados (13 do sexo masculino e 14 do sexo feminino) na pesquisa industrial e, 12 voluntários não aclimatados nos ensaios laboratoriais. Os resultados mostram que a temperatura média da pele diminui quando exposta ao ATEF, enquanto a maior diminuição foi encontrada nas mãos e na testa. Enquanto estudos anteriores medindo a temperatura retal e timpânica encontraram uma diminuição na temperatura interna, esta tese medindo a temperatura intra-abdominal do núcleo mostra uma diminuição durante os primeiros minutos de exposição, à qual se segue um aumento acima da temperatura inicial ao longo da exposição ao ATEF. O período de recuperação como os períodos de trabalho / descanso também foram discutidos. Outros estudos devem ser realizados no SCE medindo a temperatura do núcleo através da temperatura esofágica ou intra-abdominal e com mais pontos de medição para a temperatura da pele em particular nas extremidades como, por exemplo, face, dedos das mãos e dos pés).

Palavras-chave: exposição ao frio, termoregulação, indústria de alimentos congelados, armazéns de frio, sensação térmica

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ACRONYMS AND ABREVATIONS

A – Afternoon

Acc – Total accelerometry

AccX – Lateral accelerometry

AccY – Longitudinal accelerometry

AccZ – Vertical accelerometry

ACGIH – American Conference of Governmental Industrial Hygienists

BMI – Body Mass Index

BP – Blood Pressure

C – Cold

CEUP – Ethics Committee of the University of Porto

Clo – Clothing insulation factor

COPD – Chronic Obstructive Pulmonary Disease

CWHQ – Cold Work Health Questionnaire

DemSSO – Doctoral Program of Occupational Safety and Health

DIN – German Institute for Standardization

DYS, Dys – Diastolic blood pressure

EC – Ethical Committee aproval

EEG – Electroencephalogram

F – Females

FAO – UK Food and Agriculture Organization

FEUP – Faculty of Engineering of the University of Porto

G – Read from graph

H – Heavier exercise

HR – Heart Rate

IC – Informed Consent

INMET – Brazilian National Institute of Meteorology

ISO – International Organization for Standardization

L – Lighter exercise

LAETA – Associated Laboratory for Energy, Transports and Aeronautics

LSHT – Laboratory on Safety and Occupational Hygiene

LV01 – Where "LV" stands for "laboratory volunteer" and the number that follows was given for each next volunteer the next number

M – Males

MVC – Maximal Voluntary Contraction

N – Night

O – Older

PROA/LABIOMEP – Research Laboratory on Prevention of Occupational and Environmental Risks / Porto Biomechanics Laboratory

Q – Question

R – Rewarming

Res – Resting

Rh – Relative humidity

SCE – Severe Cold Thermal Environment

SEM – Electronics Sensor Module

Sk1 – Skin temperature of the left calf

Sk2 – Skin temperature of the right anterior thigh

Sk3 – Skin temperature of the left hand

Sk4 – Skin temperature of the left arm in lower location

Sk5 – Skin temperature of the left upper chest

Sk6 – Skin temperature of the right scapula

Sk7 – Skin temperature of the right arm in upper location

Sk8 – Skin temperature of the forehead

STI – Ingestible Thermal Sensors

SYS, Sys – Systolic blood pressure

Tbody – Mean body temperature

Tcore – Core temperature

Tre – Rectal temperature

Tskin, Tsk – Mean skin temperature

TSQ – Thermal Sensation Questionnaire

UFPE – Federal University of Pernambuco

UPE – University of Pernambuco

V01-D3-1 – where “V01” stands for volunteer number 1 (to each volunteer was given a code name), “D3” stands for the trial day of that specific volunteer, and the last number “1” stands for morning, while “2” for afternoon part of the trial.

WCET – The Wind Chill Equivalent Temperature

WCET – Wind Chill Equivalent Temperature

Y – younger

1 INTRODUCTION

1.1 Occupational exposure to SCE

In spite of an overall trend toward increasing global temperatures, climate models forecast more variable weather, which can result in important cold-related health consequences for humans. Increases in winter weather variability have been associated with excess morbidity and mortality across various populations and geographic locations (Conlon et al. 2011).

Exposure to cold environment is also a significant risk factor in industrial activities, present in outdoor during the winter season and indoor present in all seasons (Tochihara 2005).

The contributing factors (T. M. Mäkinen and Hassi 2009) significant for taking into consideration when exposed to cold are illustrated in the table 1.

Table 1 – Contributing factors of exposure to cold.

Climate/Exposure	**Physical activity**	**Clothing**	**Individual**	**Socioeconomic**
Temperature	Level (heat production)	Insulation	Antropometry	Housing
Relative Humidity	Type of activity	Air permeability	Age	Occupation
Wind		Water vapor permeability	Gender	Urbanization
Cold objects		Weight	Health	Transportation
Cold liquids		Ergonomics	Medication	
Darkness			Fitness	
Slipperiness			**Adaptation**	

1.1.1 Outdoor occupations

Cold exposure in outdoor activities is present in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work (T. M. Mäkinen et al. 2006), among winter sport athletic disciplines (Sue-chu 2012) and related occupations. Outdoor exposure to cold is of particular interest for regions in high latitude environments where winter seasons last for several months, as Canada, Finland, Norway, Russia or Sweden, with winter lasting for 3–7 months (T. M. Mäkinen 2007).

For the outdoor work, climatic conditions vary including changes in temperature, wind and precipitation which complicate appropriated cold protection (T. M. Mäkinen and Hassi 2009).

1.1.2 Indoor occupations

The frozen food deliver high quality, good value and safe foods with an extended storage life, helping the dietary portion control and reducing waste, offer the possibility to preserve and use seasonal foods all year round (Young et al. 2010). In emerging markets like Latin America, South East Asia and Eastern Europe, an increase demand for richer and more varied diets will occur and, importantly, increase demand for large domestic appliances such as freezers (Kennedy 2000). Further on, shifts in global economic, social and demographic trends will continue to put pressure on food supplies, as already is witnessed today, more frozen foods to be sold each year and new products introduced to swell the total sales (Artley, Reid, and Neel 2008). The structure of the labour market is constantly undergoing change, away from fresh and home-grown towards chilled and frozen food, and its future trend is shown clearly through the development in recent years (Baldus, Kluth, and Strasser 2012).

In the fresh food industry the working activities are conducted in environmental temperatures from 0ºC to 10ºC, while in the frozen food industry usually are at temperatures below -20ºC (T. M. Mäkinen et al. 2006), varying from -5°C to -30°C depending on the practical storage life and type of food to be frozen (WFLO 2008). Indoor working exposure to cold offers constant and predictable climate conditions, which facilitates cold risk management and workers cold adaptation.

For the indoor work, climatic conditions are constant and predictable, which facilitates cold risk management, but with higher exposure pose higher risk for workers, aggravating into having a chronic disease (T. M. Mäkinen and Hassi 2009).

1.2 Influence of exposure to SCE

When the human body is exposed to cold, the initial response is to preserve heat by reducing heat loss. The skin blood flow, especially in extremities is reduced by vasoconstriction (Charkoudian 2010), which leads to increased systolic and diastolic blood pressure, lowered heart rate and skin temperature in extremities (Désirée Gavhed 2003).

Severe cold thermal environment reduces core (Tskin) and skin (Tskin) temperature and therefore physical working performance, lower muscle performance, maximal grip frequency and grip strength, hand and finger dexterity, maximal voluntary contraction, while increase muscle fatigue (T Zlatar, Baptista, and Costa 2015). In cold, musculoskeletal complains and symptoms are common (Tochihara et al. 1995; Sormunen et al. 2009; Muller et al. 2012; J.J. Pilcher, E. Nadler 2002; Cheung, Westwood, and Knox 2007; Oksa, Ducharme, and Rintamäki 2002), which further on might lead to work-related pathology (T. M. Mäkinen and Hassi 2009).

It is very well documented that there is an increase mortality related to acute myocardial infarction (AMI) during the cold season (Gómez-Acebo, Llorca, and Dierssen 2013; Turin et al. 2011; Sheth et al. 1999; Chang et al. 2004; Spencer et al. 1998; Kriszbacher et al. 2009; Gill et al. 2013). Nevertheless, cardiovascular diseases can be reduced by good management program of risk factors at work (Näyhä 2002; Mitu and Leon 2011).

Different types of cold adaptations are related to the intensity of the cold stress and to individual factors such as body fat content level of physical fitness, gender, age, diet and ethnicity

(Gosselin 2013; Inoue et al. 1992; Johnston et al. 1996; Jonge 2003; B. J. Kim et al. 2013; Maley et al. 2014; Vallerand and Jacobs 1989; Yoda et al. 2008). The hypothermic general cold adaptation seems the most beneficial for surviving in the cold (Savourey, Vallerand, and Bittel 1992; Harinath et al. 2005), but the interest of the development of general cold adaptation in workers in the cold are questionable since occupational activities can be organized to avoid cold disturbances (shelter, clothes, heat sources, time sharing). For the workers working in cold environments, adaptations of extremities are beneficial, as are developing cold induced vasodilatation, improving manual dexterity and pain limits (Launay and Savourey 2009).

By a questionnaire conducted by Taylor, Penzkofer, Kluth and Strasser (Penzkofer, Kluth, and Strasser 2013), it was found that order-picking work in cold environment leads to frequent complaints, especially in the upper part of the body. Repeated, prolonged hyperpnoea with cold dry air represents a significant environmental stress to the proximal and distal airways, leading to the development of respiratory symptoms, airway hyper-responsiveness and injury, and inflammation and remodelling of the airway (Sue-chu 2012).

Workers with less years of activity seem to be more satisfied with the cold thermal ambient than veterans with more than 10 years of activity (Oliveira et al. 2014). In addition, the results highlight that the average feeling of cold and the occurrence of metabolic and other health problems are slightly higher among women. The subjective survey shows that the food distribution sector is characterised by a young population, mainly women with a short-length professional career. An analysis by gender has shown statistically significant results in terms of higher feeling of cold and less tolerance to cold among women (Oliveira et al. 2014).

The effects of occupational exposure to cold on human health documented and summarized (T. M. Mäkinen and Hassi 2009) into three main categories:

Cold-related symptoms and complains: Respiratory related (increased excretion of mucus, shortness of breath, wheezing and cough); Cardiovascular diseases related (chest pain, arrhythmias, shortness of breath); Circulatory related (colour changes in digits, pain in cold, numbness and tickling); Musculoskeletal related (pain, stiffness, swelling, restriction of movements, paresthesias muscle weakness); Dermatological related (itching, eruption of skin, pale skin, erythema, oedema);

Cold-related illnesses and diseases: Respiratory related diseases (asthma, Chronic obstructive pulmonary disease (COPD) and Rhinorrhea); Cardiovascular diseases related (coronary and other heart diseases, myocardial infarction and cerebral vascular incidents); Circulatory related (Raynaud’s phenomenon and hand-arm vibration syndrome); Muscular related (carpal tunnel syndrome, tension neck syndrome, tenosynovitis, peritendonitis); Dermatological related (cold urticaria, pernio, psoriasis and atopic dermatitis);

Cold injuries and cold associated injuries: Freezing injuries (frostbite); Non-freezing injuries (trench foot and hypothermia); Cold associated injuries (slips, trips and falls, other injuries).

Cold related symptoms and complains, illnesses and diseases as cold injuries and cold associated injuries could be managed more effectively. The aim of this work is to present the level of knowledge evidence -on the influence of severe cold thermal environment on core and skin temperatures.

1.3 Standards and recommendations for working in SCE

The International Organization for Standardization (ISO 15743:2008) give recommendations on risk and health assessment in cold environment (outdoor and indoor), and organizational preventive measures against cold risks:

- In planning phase of project: to schedule work for warmer season (for outdoor work); to check if work can be done indoors (for outdoor work); to allow more time per task with cold work and protective clothing; to provide heated space or heated shelter for recovery; to provide training and conducting complex work tasks under normal conditions; to ascertain appropriate knowledge and competence of staff; to separate goods and work stations and keep different temperature zones; to provide extra manpower to shorten and/or reduce exposure.

- Before every work shift: to check climatic conditions at onset of work; to schedule adequate work-rest regimens; to allow for individual control of work intensity and clothing; to prepare schedule and control stations (outdoors); to organize communication system (outdoors).

- During the actual work shift: to provide for break and rest periods in heated shelter; to provide for frequent breaks for hot drinks and food; to care for flexibility in terms of intensity and duration of work; to provide replacement of clothing items (socks, gloves, etc.); to provide access to extra clothing for warmth; to monitor subjective reactions (outdoors); to report regularly to foreman or base (outdoors); to provide for sufficient recovery time after severe exposures (outdoors).

Nevertheless, the ISO 15743:2008 gives only general recommendations and direct workers, foremen and occupational safety and health professionals to be trained to identify, estimate and manage the cold-related risk and health assessment.

Only one – Brazilian regulation was found limiting maximum exposure time working in cold thermal environments. When there are no regulations, safety rules can be applied by using practically proven methods for eliminating or reducing occupational risks. Guidelines were suggested by national institutions (Canadian Centre for Occupational Health & Safety (CCOHS) 2016; Occupational Safety and Health Service of New Zealand 1997; Croatian Institute for Health Protection and Safety at Work 2016; Work Safe Victoria 2008; Safe Work Australia 2011; WorkCover NSW 2001) to conduct work/task assessments, create safe work plans, and monitor conditions to protect the health and safety of workers exposed to cold temperatures.

1.3.1 Work/Rest periods

Brazilian regulation NR29 (Fundação Jorge Duprat Figueiredo de Segurança e Medicina do Trabalho 2003) for work/rest periods in cold workplaces is illustrated in the table 2.

Table 2 - Recommended Work/Rest periods in cold workplaces, example 1 – Brazil.

Air temperature (˚C)	Maximum daily exposure		
	Total daily exposure	**Maximum uninterrupted exposure**	**Recovery time**
+15.0 to -17.9	400 min (6h40 min)	4 x 100 min (1h40min)	20 min
-18.0 to -33.9	240 min (4h)	4 x 60 min (1h)	60 min
-34.0 to -56.9	60 min (1h)	2 x 30 min (0.5h)	240 min (4 h)
-57.0 to -73.0	5 min	1 x 5 min	Rest of the day
Below -73.0	Not allowed		

The UK Food and Agriculture Organization (FAO) gives recommendations for personnel working in cold stores (below -20°C), where the working period of 50 minutes should be followed by a resting period of 10 minutes (Johnston; Nicholson; Roger; Stroud 1994).

In the tables 2, 3 and 4 are given work/rest recommendations for workers exposed to severe cold thermal environment, which are properly dressed with cold protective equipment.

The German Institute for Standardization (DIN) gives recommendations for work/rest periods (DIN 33403-5 1997) as illustrated in the table 3.

Table 3 - Recommended Work/Rest periods in cold workplaces, example 2 – Germany.

Air temperature (˚C)	Maximum uninterrupted exposure (min)	Recovery time depending on the exposure (%)
-5 to -18	90	20
-18 to -30	90	30
Below -30	60	100

In Canada and New Zealand (Occupational Safety and Health Service of New Zealand 1997; Canadian Centre for Occupational Health & Safety (CCOHS) 2016), the recommendations were given for work/rest periods based on “Threshold Limit Values (TLV) and Biological Exposure Indices (BEI)” document published by the American Conference of Governmental Industrial Hygienists (ACGIH), which gives recommendations (American Conference of Governmental Industrial Hygienists (ACGIH) 2012) for working at air temperatures below -26˚C, as illustrated in the table 4.

Table 4 - Recommended Work/Rest periods in cold workplaces, example 3 - Canada and New Zealand.

Air temperature (˚C) Sunny Sky	**No noticeable wind**		**8 km/h wind**		**16 km/h wind**		**24 km/h wind**		**32 km/h wind**	
	Max Work Period (min)	**No of Breaks**	**Max Work Period (min)**	**No of Breaks**	**Max Work Period (min)**	**No of Breaks**	**Max Work Period (min)**	**No of Breaks**	**Max Work Period (min)**	**No of Breaks**
-26 to -28	Normal	1	Normal	1	75	2	55	3	40	4
-29 to -31	Normal	1	75	2	55	3	40	4	30	5
-32 to -34	75	2	55	3	40	4	30	5	Emergency work only	
-35 to -37	55	3	40	4	30	5	Emergency work only			
-38 to -39	40	4	30	5	Emergency work only					
-40 to -42	30	5	Emergency work only							
-43 and below	Non-emergency work should cease									

* This schedule applies to any 4-hour work period with moderate to heavy work activity, and with warm-up breaks of 10 minutes and an extended lunch break, all in a warm location. For light to moderate work (little physical movement), apply the schedule one step lower. For example, if the recommended maximum work period is 40 minutes on the above chart, for light work.

1.3.2 Physiological limits

The International Organization for Standardization (ISO) gives recommendations on physiological limits (ISO 9886:2004) for Tcore of a lower value of 36.0°C (when these temperatures are monitored intermittently and when exposure is going to be repeated the same day). In exceptional circumstances, the ISO standard allows lower temperatures to be tolerated for short periods:

- if subjects have been medically screened
- if the local skin temperatures are simultaneously monitored and the relevant limits are respected (concern only the pain threshold)
- if in cold situation, the minimum local skin temperature is 15°C (in particular for the extremities: face, fingers and toes)
- if the worker is authorised to leave the working situation as he pleases

While some countries give precise regulations and recommendations on work/rest periods in cold workplaces with different ranges of air temperature, the International Organization for Standardization gives recommendations only on lowest core and skin temperatures, risk and health assessment in cold environment (outdoor and indoor), and organizational preventive measures against cold risks. Both approaches appear to have advantages and disadvantages. The regulations and recommendations by countries with work/rest periods give an approach which is easy to implement, but do not consider type of work/physical exertion of the worker, therefore in some cases might result with too short or too long recovery period. The ISO 9886:2004 recommendations with lowest/highest core/skin temperatures give an approach which is difficult to implement, require complex equipment, procedures and knowledge to analyze and interpret results, but it gives the possibility to adapt exposure time according to the working activity and workers individual characteristics.

Standards for working in SCE were found to give different recommendations on maximal uninterrupted exposure and recovery time. There is a need to understand better how severe cold thermal environment influence core and skin temperatures, in order to give work-rest period recommendations based on core and skin temperature variations and recovery periods.

Research Question: “How severe cold thermal environment influence core and skin temperatures?”

1.4 Thesis design

The thesis was divided into six chapters: systematic review; methodology; industrial research; laboratory research; discussion and conclusions; and, future research.

In order to address the challenges defined by the research question, the research was divided into three research processes: Systematic Review; Industrial Research; and Laboratory Research.

The Systematic Review presented as thesis chapter, was conducted in order to build the state of the art on the influence of SCE on core and skin temperatures. It allowed obtaining important information for the design of the Methodology, with best practices of data collection and experimental work conducted in the industrial and laboratory research, analyze the results and discussions and being able to compare conclusions between analyzed articles.

The Methodology chapter was divided into 5 chapters. In the first chapter “Selection of equipment and experimental protocol development” were described phases which slowly led to the decision on the research proposal and this dissertation. It shows how research activities develop, which were the challenges, and how it resulted with the selection of the experimental protocol (described in the second part), equipment and questionnaires (third part), equipment limitations (fourth part) and data analysis (fifth part).

The Industrial Research was conducted in order to study the influence of SCE on core and skin temperatures in real working environments, where time of exposure varied depending on the activity and situation (normally between 1-10 minutes), where the working activity demanded higher physical strain and the subjects (workers) were acclimatized. Working activities and exposure to SCE varied between workers.

The laboratory research was conducted in order to study the influence of SCE on core and skin temperatures in a controlled environment, where time of exposure was for all volunteers 60 minutes, where working activities demand lighter physical strain, presenting a simulation of an industrial working activity, but with reduced weight, and non-acclimatized subjects. As all volunteers conducted a trial of 180 minutes, with exposure to SCE of 60 minutes, having same carefully controlled working activities and bigger number of subjects, it was possible to illustrate the core and skin temperature variations throughout the trial and make general conclusions on recovery period after exposure to SCE.

In the discussion and conclusions chapter, results from the articles selected by the systematic review were compared with results from industrial and laboratory researches. In the last part, the hypotheses from the research objectives were answered.

The future research chapter briefly describes future research perspectives based on the state of the art and experiences in industrial and laboratory researches.

In the thesis Appendix were enclosed: the Project proposal; the Detailed protocol sent to the Ethics committee; the Ethics Committee approval; Complementary information from the industry (total CWHQ figures; TSQ data; Brazilian Portuguese version of the Informed Consent;

Brazilian Portuguese version of the Information for the volunteer; Brazilian Portuguese version of the Participation and trial form; Brazilian Portuguese version of the CWHQ; Brazilian Portuguese version of the Thermal sensation questionnaire; Detailed protocol used in the industry); Complementary information from the laboratory (all Accelerometry and Tcore graphs; English version of the Informed Consent; Portuguese version of the Informed Consent; English version of the Information for the volunteer; English version of the Participation and trial form; English version of the Thermal sensation questionnaire).

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2 RESEARCH OBJECTIVES

Further objectives and hypothesis were determined for properly dressed subjects using cold protective equipment as defined by standards (ISO 15743 2008; ISO 20347:2012; EN 342:2004; EN 511:2006).

2.1 Objective 1

Study the influence of severe cold thermal environment on core temperature variations and its recovery period.

2.1.1 Core temperature variations

Based on ISO 9886:2004 physiological limit recommendations:

Hypothesis 1 "The core temperature decreases when workers are exposed to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and FAO recommendations:

Hypothesis 2: "The core temperature of active workers will decrease below 36.0°C after 50 minutes of exposure to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and Brazilian technical manual (Manual Técnico da NR 29):

Hypothesis 3: "The core temperature of active workers will decrease below 36.0°C after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

2.1.2 Core temperature recovery

Based on ISO 9886:2004 physiological limit recommendations and FAO recommendations:

Hypothesis 4: "The core temperature will recover only in 10 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and Brazilian technical manual (Manual Técnico da NR 29):

Hypothesis 5: "The core temperature will recover only in 60 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

2.2 Objective 2

Study the influence of severe cold thermal environment on skin temperature variations and the variations of all measured body points and its recovery period.

2.2.1 Skin temperature variations

Based on ISO 9886:2004 physiological limit recommendations:

Hypothesis 6: "The skin temperature decreases when workers are exposed to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and FAO recommendations:

Hypothesis 7: "The skin temperature of measured points in the extremities will decrease to 15.0°C after 50 minutes of exposure to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and Brazilian technical manual (Manual Técnico da NR 29):

Hypothesis 8: "The skin temperature of measured points in the extremities will decrease to 15.0°C after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

2.2.2 Skin temperature recovery

Based on ISO 9886:2004 physiological limit recommendations and FAO recommendations:

Hypothesis 9: "The skin temperatures of all measured points will recover only in 10 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

Based on ISO 9886:2004 physiological limit recommendations and Brazilian technical manual (Manual Técnico da NR 29):

Hypothesis 10: "The skin temperature of all measured points will recover only in 60 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."

2.3 Secondary objectives

Secondary objectives were to study the influence of severe cold thermal environment on:

1. thermal sensation
2. answers to the Cold Work Health Questionnaire
3. Blood pressure and heart rate
4. Relation between movement (accelerometry) and the core temperature

3 SYSTEMATIC REVIEW

Evidence of the Influence of Severe Cold Thermal Environment on Core and Skin Temperatures: a systematic review

ABSTRACT

Exposure to severe cold thermal environment (SCE) is a significant risk factor in the frozen food industry, influencing health and safety of the employees. The aim of this work is to present the level of knowledge evidence on the influence of SCE on core and skin temperatures. A review has been conducted by using appropriated keywords and expressions, searching 21 electronic databases and the references of the included articles. Only research articles with healthy subjects and considering exposure to SCE conditions (-5°C or lower) were considered. Finally, 13 articles which met the research objective and according to the inclusion and exclusion criteria were included in the systematic review. All the included studies measured core and/or skin temperatures. The main findings of this review indicate that working in SCE is and will remain an added risk factor. Further studies should be conducted in laboratory and industrial severe cold thermal environment on acclimatized and non-acclimatized subjects, in order to core and skin temperature variations and its recovery periods.

PRACTITIONER SUMMARY: This review was set out in order to study core and skin temperatures variations when the human body is exposed to environmental temperatures below -5˚C. Results vary depending on work-rest cycles, time of exposure, type of activity, gender and equipment, and are supporting studies on this topic.

Keywords: Cold exposure; Thermoregulation; Core temperature; Skin temperature; Body temperature; Cold store; Occupational health.

3.1 Methods

3.1.1 Searching strategy

The academic and clinic PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses was used in creating and modeling this article (Liberati et al. 2009). References w\ere managed using the Mendeley 1.15.3.

For searching purposes, the following keywords were defined: "cold human performance", "cold human effect", "cold human influence" and "cold human fatigue". After keywords were defined, the electronic databases were searched by title, without using quotation marks on keywords, in order to allow a different order of words in the title. Thorough databases search was conducted in engineering ("Compendex", "Inspec", "IEEE Xplore" and "ScienceDirect (eJournals)"), health ("MEDLINE (EBSCO)", "PsycArticles", "PubMed", "BioMed Central Journals", "nature.com" and "Science Magazine") and multidisciplinary area ("Current Contents", "Web of Science", "SCOPUS", "Informaworld (Taylor and Francis)", "SpringerLink", "Directory of Open Acces Journals (DOAJ)", "Emerald Fulltext", "Oxford Journals", "SAGE Journals Online", "Wiley Online Library" and "Cambridge Journals Online"). In total, 21 databases were searched thoroughly by title, using same keywords.

All articles that were connected with the topic were screened by abstract according to the exclusion and inclusion criteria, and if connected with the systematic review objective, they were downloaded.

Keywords of chosen articles were also screened, and afterwards some of them selected for a new search thorough all the 21 previously mentioned databases, by using new keywords-expressions: "cold temperature" and "cold exposure" crossing with keywords: "injury", "illnesses", "vasoconstriction", "skin temperature", "core temperature", "heart rate", "psychomotor performance", "musculoskeletal", "cardiovascular", "respiratory", "dexterity", "metabolic pressure", "blood flow", "handgrip", "body temperature", "thermography", "blood pressure" and "accidents".

Articles that were cited by the chosen articles were also screened and if relevant included in this systematic review, even if published before the year 2000.

3.1.2 Exclusion criteria

During the Meta search, the articles were excluded if published before the year 2000. The same exclusion criterion was repeated through the search of databases in engineering, health and multidisciplinary areas. Articles were also excluded if published in any other language but English. The articles were excluded if not conducting experiments on humans, if conducting experiment in cold water, ice or any other type of environment except for cold air exposure.

3.1.3 Inclusion criteria

The articles were included if they were research articles considering exposure to severe cold environment (air temperatures of -5°C or lower) with constant air temperature throughout the trial time, measured skin and/or core temperature (with the exclusion of articles which only give the temperature of a part of the body like fingers and/or face), considering normal cold protective clothing (not heating vests); and if all body was exposed to cold (not just hands and/or face).

3.2 Results

The identification process resulted with 398 articles published after the year 2000 in English language. By screening references of included articles, additional 3197 articles were found to be related to exposure to cold. Therefore, the total number of found articles was 3595. After excluding 1865 repeated articles, only 1730 articles were left to screen. By screening article titles, abstracts or being unreachable, additional 1225 articles were excluded. In total, 505 articles were screened in full text versions. Of these, 187 were excluded for not being a research article, but a review, questionnaire, report, cross-sectional study, abstract or other. Exclusion was made if articles considered exposing volunteers to cold water, ice or any other type except for cold air temperatures, which resulted with an exclusion of 151 articles. By excluding 119 articles which considered exposure to air temperatures of -5°C or higher, 48 articles were included for the final thorough screen.

After a thorough screen, 10 articles were excluded due to conducting research on patients with a history of cold intolerance, being hypertensive, with heart or respiratory diseases and 1 article due to researching the influence of touching cold materials instead of cold air exposure. Three more articles were excluded due to conducting a cold therapy. Finally, 13 articles were included in this systematic review, which is shown in the Figure 1. From those 13 articles, 2 were the same study but discussing different parameters. Therefore, in further tables, only 12 studies were shown (one integrating those 2 articles). Included articles were published between 1998 and 2013. Main results of this systematic review are shown in the Tables 5, 6, 7, 8 and 9.

Table 5 - The physical characteristics of the volunteers in the selected studies.

Reference	Number of subjects and their gender	Mean Age (years)	Mean BMI (kg/m^2)	Mean body fat (%)	Body surface area (m^2)
1 - (Kluth, Penzkofer, and Strasser 2013)	1) 15M; 2) 15M	1) 25.9±3.5 (20 to 35) 2) 55.7±6.9 (40 to 65)	1) **23.6; 2) **27.8		
2 - (Li, Alshaer, and Fernie 2009) EC,IC	8M/16F	27.1±9.0 (18 to 51)	22.4±3.1 (18 to 31)		
3 - (Oksa et al. 2004)	1) a) 4M b) 4F 2) 8M	1) a) 20.0±3.0; b) 19.0±2.0 2) 27.0±5.0	1) a) **21.7; b) **20.3 2) **24.2	1) a)11.0±2.0; b)20.0±2.0 2) 17.0±4.0	
4 - (Wiggen et al. 2011) EC,IC	12M	23.0±1.8	**23.2	12.0±2.0	1.97±0.10
5 - (T. T. Mäkinen et al. 2001) EC,IC	8M	23.0±2.0	23.0±2.0	14.0±3.0	
6 - (D. Gavhed et al. 2000) EC,IC	8M	23.5±1.6	22.9±2.5	13.6±2.6	
7 - (Dragan Brajkovic and Ducharme 2006) EC, IC	6M/6F	33.0±8.0	**25.1	20.0±4.0	1.89±0.22
8 - (Daanen 2009)EC, IC	12M	27.0±6.0	**22.4	13.5.±0.18	1.97±0.18
9 - (Kluth, Baldus, and Strasser 2012; Baldus, Kluth, and Strasser 2012)	1) 15F 2) 15F	1) 24.0±3.6 (20 to 35) 2) 53.3±6.7 (40 to 65)	1) 23.24±4.10 2) 24.6±4.9		
10- (T. G. Kim et al. 2007)IC	8M	23.1±0.8	**21.1		1.73±0.03
11- (Ozaki, Nagai, and Tochihara 2001)EC, IC	13M	20.3±1.1	**22.4		
12- (D. C. E. Gavhed and Holmér 1998)EC, IC	10M	22.4±1.8	**23.0		

*M = males, *F = females, EC = Ethical committee approval, IC = Informed consent;
**calculated BMI from the height and weight measurement results enclosed in the articles.

Table 6 - Type of working activity, meals and other measurements or requirements in the selected studies.

Ref	Eating/ Other inclusion criteria	Type of work	Other Measurements
1		order picking	
2	fully hydrated, lunch 2.0–2.5 h	sitting	
3		walking/jogging on a treadmill (1degree inclination at two different intensities, 25% and 50% maxVO2	submaximal strain
4	healthy male 18 to 35 years, height 170 to 190 cm, fat percent ≤ 16%	resting, cycling	Oxygen consumption
5		walking on a treadmill 2.8 km/h with changing inclination from 0 to 6°	
6.	not experienced cold injury	Sitting and standing	pain sensation
7		walking on a treadmill 4.8 km/h	
8		sitting	
9		order picking / frozen food / 1.6 tons of goods per hour	*1) 1.34±0.3 W/kg *2) 1.73±0.4 W/kg
10	not eat and drink 2h before the experiment	sitting 10 min, loading work 10 min, sitting 10 min	blood samples
11	not eating immediately before the trial	sitting	critical flicker frequency, urination, hand tremor, counting task, span of attention
12		walking 2 km/h, (after 50 min at -22, half of the subjects increased their walking speed to 6 km/h, while the other half wore an extra parka on top of the original wear)	Other Measurements

Table 7 - Results of the core and skin temperature from the selected studies.

Ref	**Air temperature (˚C)**	**Air velocity (m/s)**	**Time of exposure (min)**	**Mean Tcore variation (˚C)**		**Mean Tskin variation (˚C)**	
				Baseline	After exposure	Baseline	After exposure
4	-5	0.05	108		-0.47±0.21		-4.55±0.75
2	-5.8		15 (x4)**			32.6±0.9	-2.4±0.6
12	-6		90	37.2	+0.10* (37.3)	33.0	-3.2* (29.8)
3			60				27.1±0.4
5		0.2	60	36.8±0.1	L: +0.30±0.10* (37.1±0.1) H: +0.70±0.10* (37.5±0.1)	33.0±0.1	*L: -3.7±0.2* (29.3±0.2) **H: -2.8±0.2* (30.2±0.2)
8			40	37.22 G	-0.05* (37.17 G)	33.4 G	-0.8* (32.6 G)
5		1.0	60	36.8±0.1	L: +0.40±0.1* (37.2±0.1) H: +0.8±0.1* (37.6±0.1)	33.0±0.1	L: -3.3±0.2* (28.7±0.2) H: -3.2±0.3* (29.8±0.3)
7	-10	2.0, 5.0, 8.0	30 (x3)**	Res: 37.07±0.11 H:37.31±0.03	Res: -0.1±0.12 (36.97±0.12) H: +0.62±0.05 (37.93±0.05)		
8		4.0	40	37.08 G	-0.09* (36.99 G)	32.0 G	-2.0* (30.0 G)
5		5.0	60	36.8±0.1	L: +0.1±0.1* (36.9±0.1) H: +0.6±0.1* (37.4±0.1)	33.0±0.1	L: -6.6±0.3* (26.4±0.3) H: -5.9±0.3* (27.1±0.3)
8		8.0	40	37.22 G	-0.04* (37.18 G)	31.1 G	-2.1* (29.0 G)
12	-14		90	37.2	-0.10* (37.1)	33.0	-4.9* (28.1)
4	-15	0.05	108		-0.50±0.20***		No info***
3			60				27.0±0.9
8		0.2		37.5 G	-0.11* (37.39 G)	33.3 G	-1.3* (32.0 G)
8	-20	4.0	40	37.32 G	-0.20* (37.12 G)	31.3 G	-2.4* (28.9 G)
8		8.0		37.48 G	-0.23* (37.25 G)	30.3 G	-2.6* (27.7 G)
12	-22		50	37.2	+0.10* (37.3)	33.0	-5.7* (27.7)
1			80**	Y: 36.6, O: 36.9	Y: -1.3, O: -2.0		
9	-24		80**	Y: 37.0, O: 36.9	Y: -0.9, O: -1.1		
1			120**	Y: 36.6, O: 36.9	Y: -1.5, O: -2.2		
9			120**	Y: 37.0, O: 36.9	Y: -1.1, O: -1.3		
11			20 (x3)**	N: 36.8 G A: 37.0 G	N: -0.68, A: -0.55		No difference between afternoon and night
10	-25	0.2	30 (x3)**	37.3±0.1	Res: -1.1, L: -0.8, H: -0.6	32.3±0.2	-2.3 to -2.8 (29.5 to 30.0)
4		0.05	108		-0.55±0.57****		-4.81±1.26****

All experiments included in the table measured core temperature rectally, except for the experiments conducted at -24°C where the core temperature was measured by tympanum. Abbreviations: Res = resting, L = lighter exercise, H = heavier exercise, Y = younger, O = older, G= read from graph, N= night, A= afternoon

* The variation calculated between the baseline and end results information; ** Repeated cold exposures; *** At -15°C only 10/12 finished as the finger temp decreased lower than 8°C. The other dropped out after 74 and 81 min; **** At -25°C only 5/12 finished as the finger temperature decreased lower than 8°C. The other dropped out after 31, 49, 54, 79, 80, 81 and 83 min;

Table 8 - The experimental protocol, HR, BP, skin and core temperature variations of the selected studies.

Ref	Measurement	Results
1	Experimental protocol	Rewarming (R): 20.0°C; Cold (C): -24°C 1. 20 min R; 2. 80 min C1; 3. 20 min R; 4. 100 min C2; 5. 20 min R; 6. 120 min C3; 7. 20 min R
	HR (bpm/min)	While working: average additional to the baseline younger +41 bpm; older +33 bpm; individual peaks younger up to 78 bpm, older 54 Working in cold added additional 8 bpm for the younger and 3 bpm for the older (probably because of 3kg more clothing in cold - higher physical strain Average HR diagram: younger average maximum HR 191 bpm; average capacity utilization R=57%, C=62%; older average maximum HR 171 bpm; average capacity utilization R=56%, C=59% (younger had lower physical capacity than older)
	BP (mmHg)	average maximum: younger=146±20mmHg and 83±13 mmHg; older= 149±20 mmHg and 85±14 mmHg Fluctuations of ±10 mmHg (and more) that are unrelated to working in the cold are not uncommon In comparison to an additional measurement of the subjects' blood pressure at home, an increase of 15 mmHg systolic and 6 mmHg diastolic during working in the cold store could be determined.
	Local skin temp. (°C) (7 sensors)	Nose: the temp decreased to 15°C, got cold quickly as it warmed up quickly. Finger: decreased to 16°C Toe: smaller but continuous decrease in temperature during an increasing working time
	Mean core temp. (°C) (tympanum)	Baseline - younger=36.6°C; older=36.9°C younger=-1.3°C; older=-2.0°C after 80 min. younger=-1.5°C; older=-2.2°C after 120 min.
2	Experimental protocol	Rewarming: 24.4±1.0°C, 0.2m/s, 25±6%; Cold: -5.8±0.2°C, 72±4% 1. 10 min R; 2. 15 min C1; 3. 25 min R; 4. 15 min C2; 5. 25 min R; 6. 15 min C3; 7. 25 min R; 8. 15 min C4; 9. 15 min R
	HR (bpm/min)	Baseline (66.4±9.6) Cold exposure -1.0±4 (range from -7.5 to 8.9); Recovery -3.1±4.6 (range from -12.3 to 6.5) It took 25 min of rewarming for HR to reach the trial baseline level. Repeated cold exposure had a significant effect on HR decreases (greater during the first -3.5±3.4 bpm) than during the fourth (-0.7±4.9 bpm). No interaction between clothing ensemble on average changes in HR.
	BP (mmHg)	Baseline (112.8±9.8 and 72.9±8.2) Cold exposure Sys* 8.4±5.0 (range from -0.7 to 18.9); Cold exposure Dys** 7.5±4.7 (range from -3.6 to 14.0) Recovery Sys 1.3±5.7 (range from -13.0 to 11.8); recovery Dys 0.2±5.4 (range from -10.5 to 9.8)
	Mean skin temp. (°C) (7 sensors)	Baseline (32.6±0.9) Cold exposure -2.4±0.6 (range from -3.8 to -1.1); Recovery -1.5±0.5 (range from -2.6 to -0.6) Repeated cold exposure had a significant effect on mean skin temperature recovery period, not reaching the trial baseline level after 15 min of recovery. Significant clothing ensemble effect in mean skin temperature during cold exposure.
3	Experimental protocol	1. no baseline info; 2. 60 min 20.0°C; 2. 60 min 0.0°C; 2. 60 min -10°C; 2. 60 min -20.0°C
	HR (bpm/min)	Max beats/min: 60 min 20.0°C (195±3); 60 min 0.0°C (192±3); 60 min -10.0°C (191±1); 60 min -20.0°C (192±3)
	Mean skin temp. (°C) No sensor info	60 min 20.0°C (31.5±0.5); 60 min 0.0°C (27.3±0.4); 60 min -10.0°C (27.1±0.4); 60 min -20.0°C (27.0±0.9)
4	Experimental protocol	1. 20 min 22.0°C 2. 108min to 22°C, 0.05m/s OR 2. 108 min to 5°C, 0.05m/s OR 2.108 min to -5°C, 0.05m/s, OR 2. 108 min to -15°C, 0.05m/s, OR 2. 108 min to -25°C, 0.05m/s
	Mean skin temp. (°C) (10 sensors)	Decreased during cold exposure, with greatest reduction to -4.55±0.75 (-5°C) and -4.81±1.26 (-25°C)
	Local skin temp. (°C)	Finger: The large variation in temperature was due to the gloves being removed for the manual tests. At -15°C only 10/12 finished as the temp decreased lower than 8°C. The other dropped out after 74 and 81 min. At -25°C only 5/12 finished as the temp decreased lower than 8°C. The other dropped out after 31, 49, 54, 79, 80, 81 and 83 min.

<table>
<tr><th>Ref</th><th>Measurement</th><th>Results</th></tr>
<tr><td></td><td>Mean core temp (°C)
(rectal)</td><td>All exposures led to a decrease: -0.23±0.21 (22°C), -0.42±0.24 (5°C), -0.47±0.21 (-5°C), -0.50±0.20 (-15°C) and -0.55±0.57°C (-25°C)</td></tr>
<tr><td>5</td><td>Experimental protocol</td><td>Lighter exercise: 1. 60 min 20.0°C; 2. 60 min -10°C, 0.2m/s; 3. 60 min -10°C, 1.0m/s; 4. 60 min -10°C, 5.0m/s
Heavier exercise: 1. 60 min 20.0°C; 2. 60 min -10°C, 0.2m/s; 3. 60 min -10°C, 1.0m/s; 4. 60 min -10°C, 5.0m/s</td></tr>
<tr><td></td><td>HR
(bpm/min)</td><td>60 min 20.0°C (67±3)
Lighter exercise: 60 min -10.0°C, 0.2m/s (73±2); 60 min -10.0°C, 1.0m/s (75±4); 60 min -10.0°C, 5.0m/s (73±3);
Heavier exercise: 60 min -10.0°C, 0.2m/s (89±4); 60 min -10.0°C, 1.0m/s (92±4); 60 min -10.0°C, 5.0m/s (85±5);</td></tr>
<tr><td></td><td>Mean skin temp. (°C)
(18 sensors)</td><td>60 min 20.0°c (33.0±0.1)
Lighter exercise (L): 60 min -10.0°C, 0.2m/s (29.3±0.2); 60 min -10.0°C, 1.0m/s (28.7±0.2); 60 min -10.0°C, 5.0m/s (26.4±0.3);
Heavier exercise (H): 60 min -10.0°C, 0.2m/s (30.2±0.2); 60 min -10.0°C, 1.0m/s (29.8±0.3); 60 min -10.0°C, 5.0m/s (27.1±0.3);</td></tr>
<tr><td></td><td>Local skin temp. (°C)</td><td>
<table>
<tr><th></th><th>Toe</th><th>Foot</th><th>Tibia</th><th>Calf</th><th>Anterior thigh</th><th>Posterior thigh</th><th>Finger</th><th>Hand</th><th>Arm higher location</th><th>Chest</th><th>Scapula</th><th>Forehead</th></tr>
<tr><td>20°C</td><td>28.5±1.2</td><td>30.8±0.8</td><td>32.8±0.2</td><td>31.8±0.3</td><td>33.7±0.1</td><td>32.7±0.2</td><td>29.7±0.5</td><td>32.1±0.3</td><td>32.6±0.2</td><td>34.6±0.1</td><td>34.4±0.1</td><td>32.7±0.3</td></tr>
<tr><td>(L) -10°C 0.2m/s</td><td>20.8±1.1</td><td>28.7±1.2</td><td>31.6±0.4</td><td>29.0±0.6</td><td>28.0±0.7</td><td>29.2±0.3</td><td>12.9±1.0</td><td>23.8±0.6</td><td>27.3±0.4</td><td>32.1±0.6</td><td>31.2±0.2</td><td>24.1±1.0</td></tr>
<tr><td>(L) -10°C 1.0m/s</td><td>19.6±1.6</td><td>28.0±1.5</td><td>31.5±0.5</td><td>28.4±0.8</td><td>26.8±0.7</td><td>28.9±0.7</td><td>12.8±1.7</td><td>23.4±0.1</td><td>26.7±0.7</td><td>31.6±0.2</td><td>30.0±0.5</td><td>20.5±1.1</td></tr>
<tr><td>(L) -10°C 5.0m/s</td><td>18.3±0.7</td><td>26.7±1.0</td><td>29.7±0.2</td><td>28.9±0.5</td><td>21.9±0.7</td><td>29.5±0.5</td><td>10.9±1.3</td><td>21.1±0.8</td><td>25.4±0.7</td><td>28.3±0.5</td><td>30.3±0.4</td><td>11.7±1.3</td></tr>
<tr><td>(H) -10°C 0.2m/s</td><td>25.0±1.8</td><td>30.8±0.9</td><td>32.4±0.2</td><td>31.1±0.3</td><td>29.4±0.4</td><td>30.1±0.8</td><td>27.1±3.1</td><td>28.1±1.7</td><td>27.6±0.4</td><td>32.1±0.4</td><td>30.8±0.3</td><td>23.7±0.9</td></tr>
<tr><td>(H) -10°C 1.0m/s</td><td>22.4±1.7</td><td>29.3±1.6</td><td>32.0±0.6</td><td>30.7±0.3</td><td>29.1±0.3</td><td>30.9±0.6</td><td>22.5±3.8</td><td>25.4±1.8</td><td>28.2±0.5</td><td>32.3±0.3</td><td>30.2±0.3</td><td>20.2±0.6</td></tr>
<tr><td>(H) -10°C 5.0m/s</td><td>19.3±1.1</td><td>27.9±1.6</td><td>31.1±0.4</td><td>30.7±0.2</td><td>23.7±0.7</td><td>29.6±0.5</td><td>12.7±1.5</td><td>21.1±1.1</td><td>25.6±0.5</td><td>27.2±0.8</td><td>30.7±0.4</td><td>11.8±0.6</td></tr>
</table>
</td></tr>
<tr><td></td><td>Mean core temp (°C)
(rectal)</td><td>60 min 20.0°C (36.8±0.1)
Lighter exercise: 60 min -10.0°C, 0.2m/s (37.1±0.1); 60 min -10.0°C, 1.0m/s (37.2±0.1); 60 min -10.0°C, 5.0m/s (36.9±0.1);
Heavier exercise: 60 min -10.0°C, 0.2m/s (37.5±0.1); 60 min -10.0°C, 1.0m/s (37.6±0.1); 60 min -10.0°C, 5.0m/s (37.4±0.1);</td></tr>
<tr><td></td><td>Mean body temp (°C)</td><td>60 min 20.0°C (35.5±0.1)
Lighter exercise: 60 min -10.0°C, 0.2m/s (34.4±0.11); 60 min -10.0°C, 1.0m/s (34.2±0.1); 60 min -10.0°C, 5.0m/s (33.2±0.1);
Heavier exercise: 60 min -10.0°C, 0.2m/s (35.0±0.1); 60 min -10.0°C, 1.0m/s (34.8±0.1); 60 min -10.0°C, 5.0m/s (33.8±0.1);</td></tr>
<tr><td>6</td><td>Experimental protocol</td><td>Thermo-neutral preconditioning: 1. 60 min 20.0°C; 2. 60 min -10°C, 0.2m/s; 3. 60 min -10°C, 1.0m/s; 4. 60 min -10°C, 5.0m/s
Cold preconditioning: 1. 60 min -5.0°C; 2. 60 min -10°C, 0.2m/s; 3. 60 min -10°C, 1.0m/s; 4. 60 min -10°C, 5.0m/s</td></tr>
<tr><td></td><td>HR
(bpm/min)</td><td>HR decreased during first 5 min for 4-24 beats/min after exposed to cold
No correlation between the reduction of HR and the change of BP was found.</td></tr>
<tr><td></td><td>BP
(mmHg)</td><td>Comfort preconditioning (60 min 20.0°C)
30 min -10.0°C, 0.2m/s (128.5±8.3, 83.0±11.2); 30 min -10.0°C, 1.0m/s (137.0±8.1, 94.3±13.2); 30 min -10.0°C, 5.0m/s (147.0±8.1, 100.5±12.1);
Cold preconditioning (60 min -5.0°C)
30 min -10.0°C, 0.2m/s (131.5±11.7, 89.3±6.9); 30 min -10.0°C, 1.0m/s (140.5±10.4, 95.0±4.1); 30 min -10.0°C, 5.0m/s (142.8±6.6, 95.5±12.1);</td></tr>
<tr><td></td><td>Local skin temp. (3 sensors)</td><td>Forehead and nose: Significantly lower at the end of cold preconditioning. Decreased significantly with increased air velocity. When the nose quickly cooled down to a temperature between 1 and 16°C, which occurred in all conditions, the nose temp increased and decreased in a cyclical pattern.</td></tr>
<tr><td>7</td><td>Experimental protocol</td><td>1. no baseline info
10°C dry: 2. 30 min, 2m/s; 3. 30 min, 5m/s; 4. 30 min, 8m/s
10°C wet: 2. 30 min, 2m/s; 3. 30 min, 5m/s; 4. 30 min, 8m/s
0°C: 2. 30 min, 2m/s; 3. 30 min, 5m/s; 4. 30 min, 8m/s
-10°C: 2. 30 min, 2m/s; 3. 30 min, 5m/s; 4. 30 min, 8m/s</td></tr>
<tr><td></td><td>Local skin temp. (°C)</td><td>Facial temperature (nose+cheek+chin+forehead) - As each wind speed, the mean facial temp increased as the ambient temp increased. Wetting the skin during</td></tr>
</table>

Ref	Measurement	Results
		10°C exposure significantly decreased the mean facial temp resulting with its lower temp than at 0°C condition. 10°C dry: 23.7±0.4°C (2m/s); 20.0±0.5°C (5m/s); 20.0±0.5°C (8m/s) 10°C wet: 17.0±0.4°C (2m/s); 14.4±0.4°C (5m/s); 14.3±0.3°C (8m/s) 0°C: 19.5±0.6°C (2m/s); 15.4±0.8°C (5m/s); 14.4±0.7°C (8m/s) -10°C: 15.2±0.5°C (2m/s); 11.8±0.4°C (5m/s); 11.2±0.5°C (8m/s)
	Mean core temp (°C) (rectal)	For the resting subject the baseline core temperature was 37.07±0.11, while for exercising was 37.31±0.03. During -10°C measuring from 30-60 min exposure, it was stable for resting subjects at 36.97±0.12°C, while for exercising increased significantly from 37.79±0.03°C to 37.93±0.05°C. During 0°C measuring from 30-60 min exposure, it was stable for resting subjects at 36.93±0.08°C, while for exercising increased significantly from 37.74±0.04°C to 37.90±0.04°C
8	Experimental protocol	1. no baseline info 0°C dry: 2. max 60 min, 0.2m/s; 3. max 60 min, 4m/s; 4. max 60 min, 8m/s -10°C wet: 2. max 60 min, 0.2m/s; 3. max 60 min, 4m/s; 4. max 60 min, 8m/s -20°C: 2. max 60 min, 0.2m/s; 3. max 60 min, 4m/s; 4. max 60 min, 8m/s
	Mean skin temp. (3 sensors)	Decreasing with increasing exposure duration, increasing wind speed and decreasing ambient temperature. Decrease during exposure time.
	Mean core temp (°C) (rectal)	Showed an increase during the initial minutes, probably due to the combined effects of vasoconstriction and increased thermogenesis and showed a decrease afterward. Wind speed didn't affect rectal temp. Ambient temperature, however, showed an inverse effect on rectal temp.: when the ambient temperature was about 10°C lower, the rectal temperature was about 0.2°C higher (but still lower compared with the baseline (from graph).
9	Experimental protocol	Rewarming (R): 20.0°C; Cold (C): -24°C 1. 20 min R; 2. 80 min C; 3. 20 min R; 4. 100 min C; 5. 20 min R; 6. 120 min C; 7. 20 min R
	HR (bpm/min)	While working: average additional to the baseline younger +41 bpm; older +33 bpm; individual peaks younger up to 78 bpm, older 54 Working in cold added additional 8 bpm for the younger and 3 bpm for the older (probably because of 3kg more clothing in cold - higher physical strain Average HR diagram: younger average maximum HR 191 bpm; average capacity utilization R=57%, C=62%; older average maximum HR 171 bpm; average capacity utilization R=56%, C=59% younger had lower physical capacity than older
	Local skin temp. (°C)	Toe: Continuous decrease with significant difference between younger and older. The sole of the foot measured nearly constant temperatures throughout the entire working day. Finger: Similar trend as the nose with average temperatures of approximately 20°C for both aged groups. At finger temperature of less than 14°C the performance decreases.
	Mean core temp (°C) (tympanum)	Baseline - younger=37.0°C; older=36.9°C younger=-0.9°C; older=-1.1°C after 80 min younger=-1.1°C; older=-1.3°C after 120 min The core temp was not quite fully reached after a 20 min warming-up phase. On average, the core temp of both age groups decreased to 35.6°C, but there were 7 individuals in the older group whose temperature decreased under 35°C
10	Experimental protocol	Rewarming: 20.0°C, 50%; Cold: -25°C, 0.2 m/s 1. 20 min R; 2. 30 min C1; 3. 20 min R; 4. 30 min C2; 5. 20 min R; 6. 30 min C3; 7. 20 min R
	Mean skin temp. (°C) (12 sensors)	Baseline (32.3±0.2°C) As soon as the experiment started, the mean skin temperature started decreasing and kept decreasing until the experiment was completed. While going in and out of the cold environment, the temp repeatedly showed a sudden change of an average of 3°C. After last exposure (29.5 to 30.0°C)
	Mean core temp (°C) (rectal)	Baseline (37.3±0.1°C) As soon as the experiment started, the average rectal temp started decreasing and kept decreasing until the experiment was completed (p<0.01). As heavier was the work, highest was the rectal temperature, being the difference between them higher along time. -1.1°C, -0.8°C and -0.6°C lower than baseline

Ref	Measurement	Results
	Local skin temp. (°C)	Toe: at start 27 to 29°C, at end 12.5 to 14.5°C Calf: no work=30.63±0.30°C, 9kg work=29.60±0.52°C, 18kg work=27.80±0.33°C Finger: no work =8.59±0.91°C, 9kg work =9.80±1.26°C, 18kg work =9.88±0.72°C, Decrease of about 10°C after each cold exposure Arm lower: no work =28.32±0.29°C, 9kg work =29.64±0.55°C, 18kg work =29.60±0.61°C Abdominal: (32 to 34°C) Showed the smallest range of temperature change among all skin temperature conditions throughout the experiment Chest: (31 to 33.5°C)
	Mean body temp (°C)	Baseline (35.5°C) C=34.66±0.08°C, R1=34.90±0.19°C, R2=34.90±0.19°C As heavier was the work, highest was the rectal temperature, being the difference between them higher along time.
11	Experimental protocol	At night and afternoon: Rewarming: 20.0°C, 0.2m/s, 50%; Cold: -25°C 1. 10 min R; 2. 20 min C1; 3. 20 min R; 4. 20 min C2; 5. 20 min R; 6. 20 min C3; 7. 20 min R
	BP (mmHg)	Systolic and diastolic blood pressure increased in the cold room. The average diastolic blood pressure at night was higher than that in the afternoon, although there were no significant differences overall between the afternoon and the night in the average systolic blood pressure.
	Mean skin temp. (°C) (12 sensors)	Decreased gradually. No difference in the change in Tsk from the beginning to the end of the experiment between the afternoon and night exposures.
	Local skin temp. (°C)	Toe: min temp around 13.00°C in the night and 10.00°C in the afternoon. Variation was smaller than of the finger temperature. The maximal difference between afternoon and night exposures was 5.51°C. Finger: min temp around 11.82°C in the night and 8.95°C in the afternoon. The decrease in the afternoon exposures was significantly greater than those at night.
	Mean core temp (°C) (rectal)	Night: Baseline - around 36.8°C (from graph). Constantly in decrease compared with the control. For -0.68°C at the end lower than the baseline. Afternoon: Baseline - around 37.0°C (from graph). Constantly in decrease compared with the control. For -0.55° C at the end lower than the baseline.
12	Experimental protocol	1. no baseline info; 2. 90 min -6°C; 2. 90 min -14°C; 2. 50 min -22°C
	Mean skin temp. (°C) (14 sensors)	Baseline from graph seems around 33.00°C 90 min at -6°C to 29.8°C; 90 min at -14°C to 28.1°C; 50 min at -22°C to 27.7°C
	Local skin temp. (°C)	Finger temp: 90 min at -6°C to 20.1°C; 90 min at -14°C to 12.9°C; 50 min at -22°C to 10.6°C Hand temp: 90 min at -6°C to 26.8°C; 90 min at -14°C to 23.0°C; 50 min at -22°C to 24.3°C Scapula: 90 min at -6°C to 32.0°C; 90 min at -14°C to 31.1°C; 50 min at -22°C to 30.9°C
	Mean core temp (°C) (rectal)	Baseline from graph seems around 37.15 to 37.20°C 90 min at -6°C to 37.3 °C; 90 min at -14°C to 37.1 °C; 50 min at -22°C to 37.3 °C

*Sys = systolic pressure, **Dys = diastolic pressure

Table 9 - Clothing insulations factors and clothes used in the selected studies.

Ref.	Clothing insulation
1	Thermo underwear, pullover, trousers, cold-protective suit (thick jacket and long trousers), thick hat, thermo gloves, cold-insulating boots.
2	shirt, trousers and a winter coat (1.3 clo).
3	1) normal training clothing sufficient for each particular temperature; 2) wearing 1, 2 or 3 layer clothing, respectively. The estimated thermal insulation of the clothing was 0.8 (20°C), 1.18 (0°C) and 1.82 clo (-15°C).
4	Described thoroughly in the article, with clothing insulation values 1.18 (22.0°C), 2.49 (5.0°C), 2.72 (-5.0°C), 4.2(-15.0°C) and 4.27 (-25.0°C).
5	Finnish military winter clothing ensemble 'M91' (long-legged underpants, long-sleeved undershirt, fiber pile pants, shirt, socks, trousers, outer jacket, fiber pile inner mittens, nylon outer mittens, knee-high rubber boots with linings, insulated hat with earflaps basic insulation approx. 2.2 clo.
6	Shorts and the Finnish Army outfit "M91" (total insulation: 0.415 K·m2·W-1), which includes cotton long-legged underpants, long-sleeved two-rib undershirt (50% cotton/28% polychal/22% polyester), fiber pile pants and shirt (80% polyamide/20% polyester), trousers and jacket (weave, 60% cotton/40% polyamide), ankle socks (wool/synthetic fiber mix), rubber knee-high boots with wool felt-linings, fiber pile inner mittens, nylon outer mittens and cap with earflaps.
7	During 10°C dry and 10°C wet: uninsulated ski pants, wool socks, hiking boots, long, tight-fitting, cotton, honeycomb shirt; a thin, wind-resistant nylon shell; an acrylic ski hat (if requested by the subject), and a thin pair of gloves (if requested by the subject). The objective was to allow the subject to add or remove clothing as they more comfortable in all of thermal environments.
8	The standard winter work clothing of the Royal Netherlands Air force consisted of: thermal underwear, battle dress, warm overall, dickey, warm socks, work shoes, fur hat with ear flaps, leather gloves and 'trigger finger' mittens. Goggles were used to prevent freezing of the eyes. 'Camaches' were put around the ankles to prevent excessive air movement through the trousers.
9	In the chill room warm underwear, a thermo shirt, a cold-protective vest, a pair of trousers, a wool hat, knitted gloves and thermo-insulated safety shoes were used. The gloves worn were primarily provided for occupational safety reasons rather than for keeping the hands warm. In the cold store the same underwear was used, but additionally a pullover, a pair of trousers and, more importantly, a special cold protective suit were worn. This suit consisted of a thick jacket and long trousers. Furthermore, a thick wool hat, thermo socks, special thermo gloves – normally made of fleece – and cold-insulating boots were worn.
10	Trunks (86 g), long underpants (563 g), a long-sleeved shirt (304 g), socks (60 g), a pair of gloves (118 g), a hood (195 g), cold-protective trousers (888 g), and a cold-protective jacket (1227 g). The total clothing mass was 3.491 kg, and the total insulation value estimated from this mass was about 3.4 clo. The subjects also wore cold-protective boots (1293 g).
11	Trunks, long underpants, a long-sleeved sweatshirt, socks, cold-protective trousers, a cold-protective jacket, a pair of gloves, and a hood. The total clothing mass was 3.26 kg, and the total insulation value estimated from this mass was about 2.3 clo. The subjects also wore cold-protective boots 1.5 kg.
12	The subjects were dressed in a multi-layer cold-weather clothing ensemble with a basic insulation value (I#-) of 2.23 clo (0.346 K·m2·W-1). The thermal insulation of the clothing ensemble was measured on a static thermal mannequin (ISO/DIS- 9920, 1988). The ensemble comprised briefs (100% polypropylene), long-legged and long-sleeved underwear (100% polypropylene), knitted socks (wool/polyester), fiber pile jacket and trousers (100% polyamide), coverall and jacket (cotton/polyester), knitted cap, heavy insulated leather glove and fiber pile mitten, scarf and boots. A parka, providing additional insulation of 0.7 clo, was added to the original clothing ensemble for the last 50 min of the exposure at the lowest temperature.

In the included articles, 8 conducted the experiments just on male volunteers (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; T. T. Mäkinen et al. 2001; Kluth, Penzkofer, and Strasser 2013; T. G. Kim et al. 2007; D. Gavhed et al. 2000; D. C. E. Gavhed and Holmér 1998; Daanen 2009), 3 of them conducted on both genders (Oksa et al. 2004; Li, Alshaer, and Fernie 2009; Dragan Brajkovic and Ducharme 2006), while 2 just on female volunteers (Baldus, Kluth, and Strasser 2012; Kluth, Baldus, and Strasser 2012).

Most of the articles gave the information on volunteer physical characteristics, BMI was given by 5 articles (T. T. Mäkinen et al. 2001; Li, Alshaer, and Fernie 2009; Kluth, Baldus, and Strasser 2012; D. Gavhed et al. 2000; Baldus, Kluth, and Strasser 2012), weight and height through which the BMI was calculated by 8 articles (Dragan Brajkovic and Ducharme 2006; Daanen 2009; D. C. E. Gavhed and Holmér 1998; T. G. Kim et al. 2007; Kluth, Penzkofer, and Strasser 2013; Oksa et al. 2004; Ozaki, Nagai, and Tochihara 2001; Wiggen et al. 2011).

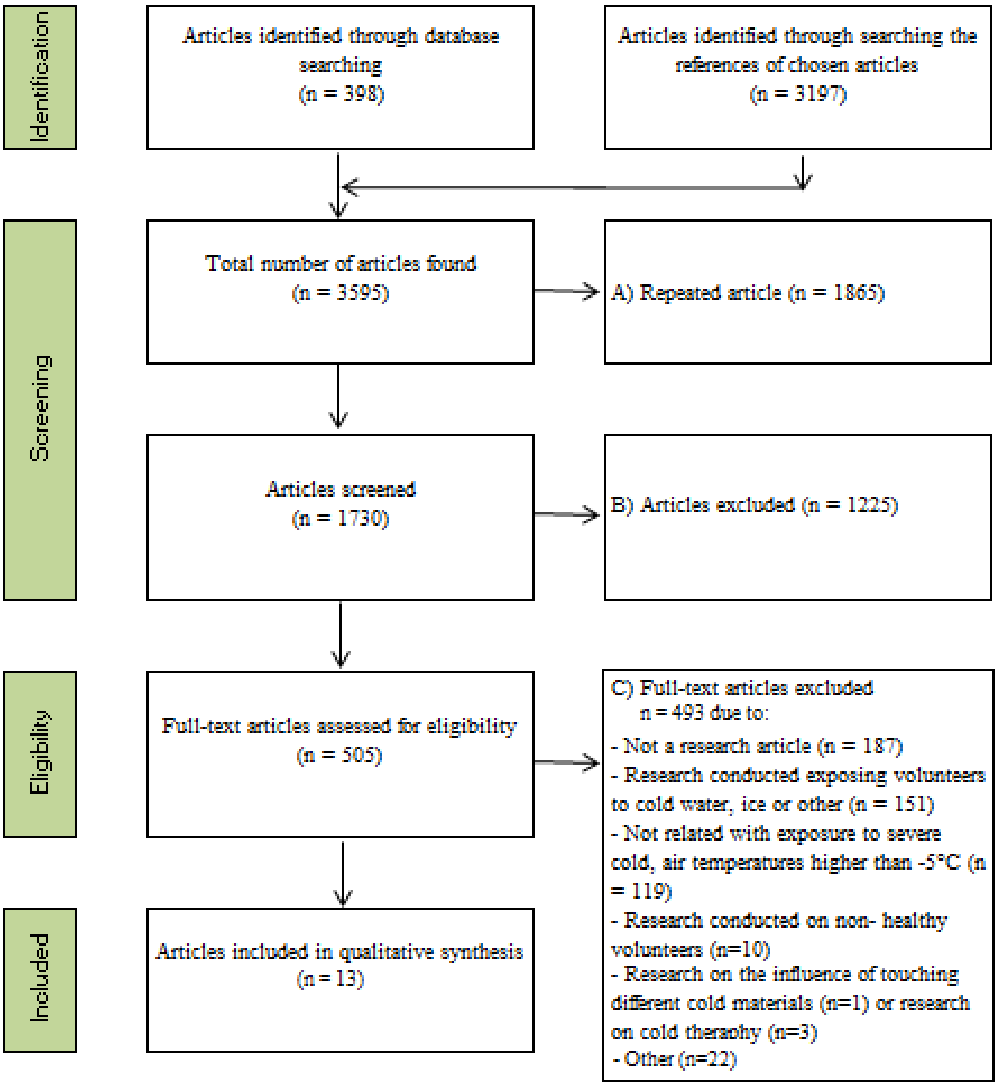

Figure 1 - Selection of studies: summary of studies in order of level of evidence, with extracted data.

If volunteers were cigarette smokers was assessed by 3 articles (Li, Alshaer, and Fernie 2009; D. Gavhed et al. 2000; Dragan Brajkovic and Ducharme 2006). The medical control was conducted in one article (Wiggen et al. 2011). Medicine taking was considered by one article (Li, Alshaer, and Fernie 2009). The separation between tests was considered in 5 articles (Dragan Brajkovic and Ducharme 2006; D. C. E. Gavhed and Holmér 1998; D. Gavhed et al. 2000; Kluth, Penzkofer, and Strasser 2013; Ozaki, Nagai, and Tochihara 2001). Preconditioning time and air temperature was considered in 8 articles (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; T. T. Mäkinen et al. 2001; Li, Alshaer, and Fernie 2009; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; Baldus, Kluth, and Strasser 2012), all of them considering comfort temperatures from 18 to 25°C, having 40% relative humidity on 25°C and 50% relative humidity on 20°C. Five of them used 20 minutes for the acclimatization period (Wiggen et al. 2011; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; Baldus, Kluth, and Strasser 2012). Four of the included articles considered sitting (Ozaki, Nagai, and Tochihara 2001; Li, Alshaer, and Fernie 2009; D. Gavhed et al. 2000; Daanen 2009), four walking (Oksa et al. 2004; T. T. Mäkinen et al. 2001; D. C. E. Gavhed and Holmér 1998; Dragan Brajkovic and Ducharme 2006), one cycling (Wiggen et al. 2011) and four order picking or loading type of working activity (Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; Baldus, Kluth, and Strasser 2012).

The experimental conditions in the selected studies were thoroughly illustrated in the table 8. The most measured parameters were the skin temperature, recorded in 10 articles (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; Oksa et al. 2004; T. T. Mäkinen et al. 2001; Li, Alshaer, and Fernie 2009; Kluth, Penzkofer, and Strasser 2013; T. G. Kim et al. 2007; D. Gavhed et al. 2000; D. C. E. Gavhed and Holmér 1998; Daanen 2009), and Tcore, also included in 10 articles (Baldus, Kluth, and Strasser 2012; Dragan Brajkovic and Ducharme 2006; Daanen 2009; D. C. E. Gavhed and Holmér 1998; T. G. Kim et al. 2007; Kluth, Baldus, and Strasser 2012; Kluth, Penzkofer, and Strasser 2013; T. T. Mäkinen et al. 2001; Ozaki, Nagai, and Tochihara 2001; Wiggen et al. 2011), and the heart rate in 7 articles (Oksa et al. 2004; T. T. Mäkinen et al. 2001; Li, Alshaer, and Fernie 2009; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; D. Gavhed et al. 2000; Baldus, Kluth, and Strasser 2012) and blood pressure in 4 articles (Ozaki, Nagai, and Tochihara 2001; Li, Alshaer, and Fernie 2009; Kluth, Penzkofer, and Strasser 2013; D. Gavhed et al. 2000).

Metabolism/oxygen consumption was recorded in 6 articles (Wiggen et al. 2011; Oksa et al. 2004; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; D. Gavhed et al. 2000) and thermal sensation in 8 articles (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; T. T. Mäkinen et al. 2001; Li, Alshaer, and Fernie 2009; T. G. Kim et al. 2007; D. Gavhed et al. 2000; D. C. E. Gavhed and Holmér 1998; Daanen 2009). In 6 of the included articles some other types of measurements were conducted (Baldus, Kluth, and Strasser 2012; D. Gavhed et al. 2000; T. G. Kim et al. 2007; Kluth, Baldus, and Strasser 2012; Oksa et al. 2004; Ozaki, Nagai, and Tochihara 2001). Type of working activity, meals and other measurements or requirements in the selected studies were thoroughly illustrated in the table 6.

In total 8 articles considered the air movement velocity. Clothing insulations factors and clothes used in the selected studies were thoroughly illustrated in the table 9.

3.3 Discussion

Several parameters influence the human response to severe cold thermal environment. Beyond the thermal environment conditions (air temperature, relative humidity and air movement velocity), there is the time of exposure, part of the day (morning/afternoon/night), type of activity (lighter or heavier exercise), physical characteristics of the human body (gender, age, height, weight, body fat), sleeping hours, consumption of alcohol, coffee, tea, to be a cigarette smoker, physical exertion previous to the exposure, the food and drinks consumption, illness history, medication currently taking, clothing insulation, acclimatization and other.

3.3.1 Blood pressure and heart rate

The blood pressure increases in all included studies, which is thoroughly illustrated in the table 8. One of the factors influencing this increase (both systolic and diastolic) is the air velocity (D. Gavhed et al. 2000). It was also found that the average diastolic blood pressure is higher during the night compared with afternoon, while there was no change in the systolic blood pressure (Ozaki, Nagai, and Tochihara 2001). The heart rate was found to be increasing in 4 articles (T. T. Mäkinen et al. 2001; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; Baldus, Kluth, and Strasser 2012) conducting order picking and walking activities, and decreasing in 2 articles (D. Gavhed et al. 2000; Li, Alshaer, and Fernie 2009) conducting sitting and walking activities, illustrated in table 8. Strong effects on the sympathetic nervous system and its cardiovascular effect on organs were found with: cold exposure on face and with inhalation of cold air. Forehead cooling induces a stronger increase in muscle sympathetic nerve activity but it decreases heart rate. Thus, activation of muscle sympathetic outflow most likely coincides with parasympathetic activation of the cardiac autonomic nervous system (Heindl et al. 2004). Also a diastolic blood pressure increase more during exposure to cold wind after comfort (thermo-neutral) temperature preconditioning, compared to cold preconditioning (D. Gavhed et al. 2000). The protection of the head from cold was found to be an easy way to reduce the sympathetically mediated surge of blood pressure in young adults. Systolic and diastolic blood pressures increased more pronouncedly in normotensive individuals when a head protection (hat) was not used during cold exposure. Wearing hats also promoted faster recovery of forehead skin temperature and blood pressure during the recovery period (Li, Alshaer, and Fernie 2009).

3.3.2 Skin temperature

The mean skin temperature decreased with increasing exposure duration, increasing wind speed and decreasing the environmental temperature which is shown in tables 7 and 8. It started decreasing when the experiments started and continued decreasing until the experiments were completed. In Mäkinen (2001) experiment the decrease was highest after 60 min of exposure to -10.0°C, with an air movement velocity of 5.0m/s, decreasing the mean skin temperature to 26.4±0.3°C (T. T. Mäkinen et al. 2001). In the experiments with multiple cycles of exposure to cold, with recovery at room temperature, the mean skin temperature increased rapidly between the re-warming and the new period of exposure to cold, which ranged up to 3°C. No difference was found in its change from the beginning to the end of the experiment between the afternoon and night exposures (Ozaki, Nagai, and Tochihara 2001).

However, peripheral skin temperature at night was found to be higher than that in the afternoon. So, the subjects were less likely to feel cold or pain sensation in the periphery at night, leading to an increased risk of both hypothermia and accidents for those who work in night period (Ozaki, Nagai, and Tochihara 2001).

One of the included articles concluded that an optimization should be made in severe cold stores (Baldus, Kluth, and Strasser 2012). In the same direction four articles (Baldus, Kluth, and Strasser 2012; T. G. Kim et al. 2007; Kluth, Baldus, and Strasser 2012; Kluth, Penzkofer, and Strasser 2013) concluded that proper spacing and timing of work-rest periods were important for the optimization of the work in cold environments. One of them (Kluth, Penzkofer, and Strasser 2013) found that an interval of 20 min at approximately +20°C during breaks was not sufficient to ensure a complete recovery of the skin temperature for all individuals. Therefore, warming-up breaks above 20 min at 20°C were suggested for subjects working in cold stores at -24°C for more than 80 minutes (Kluth, Penzkofer, and Strasser 2013). This was in accordance with a previous research (Penzkofer, Kluth, and Strasser 2013), which showed that after an exposure to -24°C, a warming-up break of 20 min was not enough for the subjects to stop the cold sensation in some body parts. An appropriated work-load seems to be an effective way of maintaining the mean body temperature and the temperature of extremities in a cold environment (T. G. Kim et al. 2007; Virokannas 1996a). In addition, metabolic heat production should be maintained by at least a moderate level of physical activity over time as well as tasks planned in order to minimise the exposure of bared parts (Rintamäki et al. 2004). It is known that the thermal resistance is higher in active individuals (Ducharme, Brajkovic, and Frim 1999). It was also found that current protective clothing used at severe cold temperatures lead to a reduction of body and skin temperatures, especially in the extremities, and that gloves and boots should be improved (Rissanen and Rintamäki 2007; Wiggen et al. 2011; Rintamäki et al. 2004; Baldus, Kluth, and Strasser 2012; Kluth, Baldus, and Strasser 2012) in order to maintain adequate performance and comfort during long exposures.

As the extremities are found to be one of the main concerns in maintaining performance at low temperatures, some studies focused on that particular problem (Wiggen et al. 2011; T. T.

Mäkinen et al. 2001; Daanen 2009; T. G. Kim et al. 2007; D. C. E. Gavhed and Holmér 1998). In one of this studies (T. T. Mäkinen et al. 2001) eight males were submitted for 1 hour at comfort environmental conditions (20°C, 0.2m/s). No great difference between the toe (28.5±1.2°C) and foot (30.8±0.8°C) skin temperature was found. However, when they were submitted at severe cold environmental conditions (-10°C, 0.2m/s), the toe skin temperature (20.8±1.1°C) decreased much more compared with the foot (28.7±1.2°C) skin temperature (T. T. Mäkinen et al. 2001). Same reaction was found to be present in fingers compared with hand skin temperature, where, even being so close body parts, the finger temperature decreased from 29.7±0.5°C to 12.9±1.0°C while the hand skin temperature decreased much less, from 32.1±0.3°C to 23.8±0.6°C. Finger temperature was found to be an important indicator of hand and finger dexterity, leading to severely impaired manual performance when below 20°C (Wiggen et al. 2011) or as concluded by another research, below 14°C (Daanen 2009). Nonetheless, two of the included articles concluded that manual dexterity tasks were not correlated with the mean body temperatures (T. G. Kim et al. 2007; Daanen 2009). The loading work was not found to increase the finger skin temperature, but the opposite, cooling and therefore a reduction in manual dexterity, while the mean body temperature increased, making the subjects feel less cold (T. G. Kim et al. 2007).

The Wind Chill Equivalent Temperature (WCET) were found to be a good indicator for manual performance decrease in combination with exposure duration for the WCET range of 1 to –34°C and exposure time of up to one hour (Daanen 2009). The WCET index might be used for evaluations in different industries with severe cold environments, where a reduced manual dexterity may decrease work performance and productivity, and increase the risk of accidents (T. G. Kim et al. 2007).

The limit criteria for extremity cooling should be introduced in further prediction models, in order to make the assessment of cold stress more complete and improve manual performance (D. C. E. Gavhed and Holmér 1998). Indirectly, torso heating was found to be an effective way for maintaining toes and fingers temperature around 22-25°C for 3h at a air temperature of -25°C (Dragan Brajkovic, Ducharme, and Frim 2001; Dragan Brajkovic and Ducharme 2001; Dragan Brajkovic and Ducharme 2003; Ducharme, Brajkovic, and Frim 1999) and at -15°C (D Brajkovic, Ducharme, and Frim 1998). Indirect heating was considered as a superior method of maintaining dexterity in the cold where the toes and deep body are kept warm, and tasks could be done comfortably barehanded. The primary drawback to indirect hand heating is a greater heater power requirement. As the toes, finger and hand temperatures where maintained high, the dexterity was better as concluded by all the mentioned articles.

Nose skin temperature was significantly higher in exercising subjects when compared to resting subjects, even though there was no significant difference in face temperature (excluding the nose) between conditions. Therefore, this finding suggests that acral regions of the face, such as the nose, are more sensitive to changes in the thermal state of the body, and hence will stay warmer compared with other parts of the face during exercise in cold (Dragan Brajkovic and Ducharme 2006). Facial pain was reported when facial skin temperature decreased down to 0°C, reported after 30 minutes exposure to -10°C on wind speed 1-5 m/s (D. Gavhed et al. 2000) after the preconditioning period. The face temperature increased when the environmental temperature increased, however when wind speed increased, the percentage of subjects showing a facial cold-induced vasodilation decreased.

Wetting the skin during 10°C exposure significantly decreased the mean facial skin temperature to a value similar to the facial skin temperature observed during the 0°C exposure (Dragan Brajkovic and Ducharme 2006).

3.3.3 Mean body temperature

The mean body temperature was found to decrease below 35°C after 60 min of walking at -10°C with 0.2 m/s air movement, and decreasing faster by increasing the air velocity (T. T. Mäkinen et al. 2001). It was also found to decrease below 35°C after 4 consecutive 30 min exposures to -25°C, with re-warming periods of 20 min at 20°C. The current literature has described the mean body temperature decreasing to 32-35°C as mild form of hypothermia (general freezing), and to appear with shivering, tachycardia, tachypnea and slowness of ideation and compensated dysarthria (Golant et al. 2008; Mitu and Leon 2011).

Nevertheless human thermoregulatory responses can be modified after a period of exposure to cold conditions. It was observed that subjects had developed a hypothermic general cold adaptation characterized by a decreased Tre (-0.5°C), a decreased Tsk (-0.5°C) with no changes in the metabolic heat production (Savourey, Vallerand, and Bittel 1992). The author concluded that through three indicators (changes in the metabolic rate, rectal and skin temperature) it is possible to quantify the adaptation level, including local cold adaptation of the extremities (Savourey, Vallerand, and Bittel 1992). Cold exposures increase cold tolerance and prevent cold injuries (Harinath et al. 2005).

3.3.4 Core temperature

When exposed to cold, the core temperature decreased in 6 studies (7 articles) (Baldus, Kluth, and Strasser 2012; Daanen 2009; T. G. Kim et al. 2007; Kluth, Baldus, and Strasser 2012; Kluth, Penzkofer, and Strasser 2013; Ozaki, Nagai, and Tochihara 2001; Wiggen et al. 2011) and to increased in 3 studies (Dragan Brajkovic and Ducharme 2006; D. C. E. Gavhed and Holmér 1998; T. T. Mäkinen et al. 2001) which is shown in tables 7 and 8. In the studies where the working activity was sitting, order picking or loading, the core temperature was decreasing, while in studies where the working activity was walking on a treadmill, the core temperature was increasing. As the core temperature in the "increasing core temperature articles" was measured rectally, the explanation might be found in the production of heat from the local muscles, for which Tre is directly affected, and therefore it is higher when the work is performed with the legs than when it is carried out exclusively with arms (ISO 9886 2004). By several included articles it was concluded that the rectal temperature was highest when the working activity was heavier (T. T. Mäkinen et al. 2001; T. G. Kim et al. 2007; Dragan Brajkovic and Ducharme 2006). The elevation of heat production by a heavier exercise level retained both core and skin temperatures at a higher level in comparison to a lower exercise level (especially in the hands and fingers), but the metabolic rate was not found to be an important factor to take in consideration for calculating the Wind Chill Index by one of the included articles (T. T. Mäkinen et al. 2001). When exposed to cold, the core temperature was found to decrease more in older than in younger subjects, as the core temperature decreased much more in male compared to female subjects (Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; Baldus, Kluth, and Strasser 2012). However, conclusions on the difference between genders should be done with caution, as the phase of the menstrual cycles was not considered in articles with female volunteers. During the night, the work should be avoided as it was noticed a decrease in the rectal temperature, manual performance and an increase in diastolic blood pressure (Ozaki, Nagai, and Tochihara 2001). Nevertheless, both rectal and tympanic temperatures were found not to be relevant for the assessment of thermal strain in cold thermal environment (ISO 9886 2004), therefore there is still no relevant knowledge on the influence of severe cold thermal environment on human core temperature throughout the exposure to SCE.

3.4 Limitations of the review and from the found studies

The searching for articles was limited to the used keywords and to the articles in the references of the selected ones. Further limitations of this systematic review lay in bias factors which were not considered in the included articles. Many included studies didn’t consider if volunteers were cigarette smokers, their illness history, didn’t conduct a medical control, didn’t consider if the volunteers were taking medications, what they were eating previous to participating to the experiments. Neither one of the included articles didn’t consider if the volunteers consumed alcohol (Yoda et al. 2008), coffee (B. J. Kim et al. 2013) or tea (Gosselin 2013) prior to participating in the experiments, what was their physical exertion, sleeping hours, which might have influenced the results of the experiments. The included articles which conducted experiments on female volunteers didn’t consider the follicular phase of the menstrual cycle, for which was found that the phase greatly influence the results (Jonge 2003). Some of the articles didn’t give any information on the physical characteristics of the included volunteers (BMI, weight, height, body fat or body surface) which is crucial for any kind of conclusions. Separation between tests is another important factor as different exposure air temperatures might lead to the acclimation of the volunteers, therefore should be considered in further experiments of this type. Not all of the included articles had the approval from an ethics committee or/and the informed consent signed by their volunteers. In the included articles, the core temperature was measured just by using measuring techniques which were found not to be relevant for the assessment of thermal strain in cold thermal environments (ISO 9886 2004).

3.5 Conclusions

Exposure to severe cold environment is and will remain a significant risk factor in working environments. Further studies should include working activities present in real life conditions exposed to severe cold thermal environment, both for outdoor (e.g. standing, walking, running) and indoor (in the industry or conducting laboratory simulations with real working movements and activities). Studies should be conducted with well specified volunteer physical characteristics with all of the mentioned (if possible) bias factors, taking in consideration both genders, differently aged people, acclimatized and non-acclimatized, exposed to different air temperatures, air velocities and time of exposure, specifying clothes used for their protection and the physical exertion needed for the task accomplishment. Further, core temperatures should be measured through oesophageal or intra-abdominal temperature, as the rectal, oral, tympanic, auditory canal and urine temperature were found not to be relevant for the assessment of thermal strain in cold thermal environment. All present studies conducted in cold thermal environment used rectal and tympanic measurements, where some show a decrease and some increase in core temperature

Further studies should be conducted in laboratory and industrial severe cold thermal environment on acclimatized and non-acclimatized subjects, in order to core and skin temperature variations and its recovery periods. Future studies should measure oesophageal or intra-abdominal core temperature and skin temperatures on at least 8 points of the body, and consider different physical exertion activities.

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4 GENERAL METHODOLOGY

4.1 Preliminary phases of the experimental research

4.1.1 1st Phase

First perspectives on equipment and experimental protocols were gathered by assisting in military experiments at comfort and hot thermal environment. Afterward by volunteering in experiments where was measured the electrical activity of the brain (EEG) in comfort and hot thermal environments.

4.1.2 2nd Phase

The mentors have been chosen and research proposal has been written on the theme "Influence of Moderate Cold Thermal Environment on Human Fatigue and Performance".

The first experiment was conducted on 6 non-acclimatized male volunteers in moderate cold with air temperature 4ºC and relative humidity 55%. The working activity was a simulation of a repetitive work in an apple industry: shifting apples from one crate to another and moving the crates in a circle. The EEG was used during all the trial, while thermographic photos were taken after 5, 15 and 35 minutes exposure to moderate cold.

The second experiment was conducted on 5 non-acclimatized female volunteers in moderate cold with air temperature 10ºC and relative humidity 30%. The working activity was a simulation of a repetitive work in a cheese industry: simulating packing of 1kg of cheese for 15 minutes, with a total exposure of 40 minutes. Thermography photos and a coin dexterity tests were conducted in pauses, while not doing the packing repetitive task.

The second phase resulted with two publications: "Cognitive working performance in moderate cold thermal environment: a systematic review" (Tomi Zlatar 2015) *and "Changes in face and hands skin temperatures during exposure to moderate cold thermal environment" (T. Zlatar, Vardasca, and Marques 2015).*

4.1.3 3rd Phase

After conducting a short review, after concluding that many questions still need to be answered in severe cold thermal environment, it was decided to change the research proposal to "Influence of Severe Cold Thermal Environment on Core and Skin temperatures". It was decided to conduct studies in the laboratory climatic chamber which lowest temperature is -20°C, where the trial can be conducted in a controlled environment with controlled tasks and exposure time.

Further on, it was decided to conduct trials on workers from the frozen food industry to study the influence of severe cold thermal environment where subjects are conducting real industrial activities and are exposed to SCE depending on the process requirements.

It was decided that as volunteers were ingesting thermometer telemetry capsules, that they should be medically screened (select volunteers which are healthy or/and don't have medical contraindication to the experiment, namely regarding to the heart diseases, vascular diseases, respiratory diseases, gastrointestinal diseases (in particular the diverticular disorder), intolerance to cold, cold urticaria, other forms of urticaria or angioedema, musculoskeletal alteration, allergies, illness history and medications currently taking. Additional medical examinations should be selected whenever clinical doubts emerged.

The study was approved by the Ethics Committee of the University of Porto (CEUP), approval number: 06/CEUP/2015 (enclosed in the appendix 3).

The trials were aborted if: the subject felt any symptoms such as dizziness, nausea and general malaise; the core body temperature, measured by the sensors went lower than 36ºC (ISO 9886 2004); the local skin temperature (in particular for the extremities: face, fingers and toes) got to 15ºC (ISO 9886 2004).

The first SCE protocol test

The first SCE protocol test was conducted on two volunteers at comfort temperatures (at 22°C, 60% Rh[1]). The trial had 7 phases as illustrated in the tables 10 and 11, but for each phase inside the climatic chamber with duration of 30 minutes, and total trial time of 2.5 hours. After examining one subject, some changes and adaptations were made, namely regarding the resting period between exposures, order in measuring parameters and documents and questionnaires. In the second protocol test, the both subjects complained on the difficulty of staying concentrated and being uncomfortable to count the number of boxes they passed from one table to the other for all the measuring period. The subjects also complained on the duration of the experiment, the repetitiveness of the task, that it was uncomfortable to wear the oxygen consumption mask for such a long period. The core body temperature of the second subject decrease from 37.3 to 36.5, he felt dizzy, as he described, due to fast and long term turning while conducting the task. The experiment was aborted as the subject reported symptoms such as dizziness, nausea and general malaise. Later on, on the additional medical control, it was concluded that it might be due to the light meal and long non-eating period, and due to the subjects taking anti epiletic drugs (anti depressant medication).

[1] Relative humidity – Rh.

The second SCE protocol test

The second SCE protocol test was conducted on two volunteers. Each phase in the climatic chamber was shortened from 30 to 20 minutes, and the total trial time from 2.5 to 2 hours. The task of counting the boxes was excluded. As carbohydrates provide the major fuel for prolonged continuous exercise and high intensity work (Bell, Cort, and Cox 2005), a note regarding eating breakfast with carbohydrates was enclosed in the informational guide for subjects. The experiments were divided into two studies, one conducting the repetitive task at the comfort thermal environment at air temperature 22°C and 60% Rh and severe cold thermal environment at air temperature -20°C. Subjects were exposed during 3 phases of 20 min to the comfort or severe cold thermal environment. The resting period between exposures was 10 minutes at room temperature varying from 20 to 28ºC. Each trial was conducted during at least 2 hours, as it is illustrated in the tables 10 and 11.

Table 10 - Phases in comfort thermal environment experiments.

	Room	Climatic chamber	Room	Climatic chamber	Room	Climatic chamber	Room
COMFORT	1	2	3	4	5	6	7
	20’	20’	10’	20’	10’	20’	20’
	20 to 28ºC	22°C	20 to 28ºC	22°C	20 to 28ºC	22°C	20 to 28ºC
	Total = 2 hours						

Table 11 - Phases in severe cold thermal environment experiments.

	Room	Climatic chamber	Room	Climatic chamber	Room	Climatic chamber	Room
COLD	1	2	3	4	5	6	7
	20’	20’	10’	20’	10’	20’	20’
	20 to 28ºC	-20°C	20 to 28ºC	-20°C	20 to 28ºC	-20°C	20 to 28ºC
	Total = 2 hours						

The second SCE protocol test was first conducted in comfort thermal environment in order to avoid the subject acclimatization to cold, because next day, if possible, the volunteer would do the trial in severe cold thermal environment (as a bigger gap between two experiments might result in changing of the subject’s health condition). In both studies the subjects conducted the same type of movement: Putting three boxes (each weighting 5 kg), one by one, from the first table (ergonomically adapted height) on their left, to the second table on their right (always in the same way and order, doing the same type of movement in the similar velocity. After putting all of the boxes from the left to right side, the subject walked to the other side and turn, facing the table two (now with all the boxes) on its left, and the table one on his right. The subjects repeated the same task putting the boxes from the left to the right table conducting the same type of repetitive movement during each 20 min of exposure. The activity and type of movement is illustrated in the figure 2:

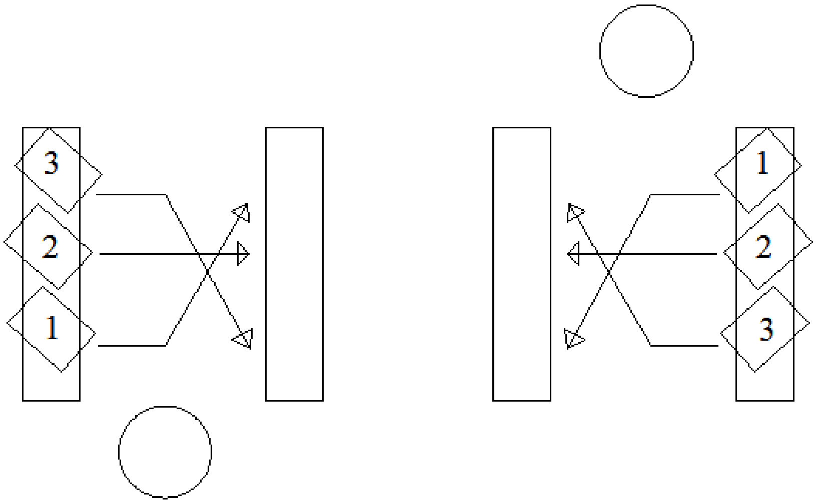

Figure 2 - Activity and type of movement.

The experiments were conducted measuring intra-abdominal core and skin temperatures, heart rate, maximal voluntary contraction (MVC) using non-intrusive equipment for measuring force output, systolic and diastolic blood pressure, answering the TSQ, and measuring oxygen consumption throughout the experiment in the comfort trial. Oxygen consumption mask couldn't work at that low air temperatures (-20ºC), therefore when conducting the experimental trial in SCE, the oxygen consumption was measured at room temperature while seated for only 2 minutes each time the blood pressure was measured.

After each phase, after the subjects exited the climatic chamber, the MVC and blood pressure were measured and after making sure the period of 10 minutes passed, the subject entered back the climatic chamber and the process was repeated as in the first phase.

The climatic chamber was not working properly at -20°C, which is the lowest temperature on which it works. Therefore a study has been conducted on climatic chamber test in order to understand it better.

The fourth phase resulted with one publication: "Physical working performance in cold thermal environment: A short review" (T Zlatar, Baptista, and Costa 2015).

4.2 Selected experimental protocol

The selected protocol will be in detail presented in the laboratory research chapter.

One week before the experiment was conducted, the research team met the subjects for the first time, explaining the comprehensive detail and purposes of the study and possible risks of the participation, getting general and lifestyle information of the subjects, scheduling the medical control and giving the instructional flyer to the subject with short explanation on the purpose, benefits, equipment which will be used, kind of food and drinks to consume and avoid and clothes to wear for each experimental session. After conducting the medical control and being sure the subjects meet all the physical characteristics, the informed consent was read and signed and the experimental days were scheduled. One day before the experimental day the research team met the subjects again, asking for health conditions changes which might have occurred. The core body temperature pill was given to the subjects and an explanation was given on how and when to ingest the pill. The subjects were reminded on all important information. The equipment was checked and the climatic chamber was set at a desired air temperature and relative humidity.

4.2.1 The climatic chamber organization

In the climatic chamber, there were four main points: A) the table on which each session started and ended, on which three standard A4 paper boxes were situated (each weighting 5 kg); one box with 12 crumpled papers; and two pairs of plastic bottles with glass balls inside them (each pair weighting 0.8 kg; B) one cabinet with three shelves on different levels (shelf 1 – 10 cm, shelf 3 - 80 and shelf 5 - 150 cm from the ground); C) one cabinet with two shelves on different levels (shelf 2 - 45 and shelf 4 - 115 cm); and D) part of the chamber with two papers taped on the wall: one with the experimental protocol in order to remind the volunteers about the tasks that follow; and two with the thermal sensation questionnaire and panels with numbers from -4 to +4 in order to show to the researcher their answers.

4.2.2 Before entering the climatic chamber

The trials were aborted if: the subject felt any symptoms such as dizziness, nausea and general malaise; the core body temperature, measured by the sensors went lower than 36ºC (ISO 9886 2004); the local skin temperature (in particular for the extremities: face, fingers and toes) got to 15ºC (ISO 9886 2004).

On the experimental day, the research team first checked the air temperature and relative humidity inside as outside the climatic chamber. Then the computers were turned on, programs opened, all equipment, questionnaires and documents were checked one more time. Twelve non smokers subjects participated in the laboratory tests in severe cold thermal environment at -20˚C. The volunteers were met at 09:15, and the core body temperature pill was checked in order to know if it is functioning and still inside the subject. Then their height and weight were measured leaving just the underpants on them. Their body was cleaned with alcohol on all points where the skin temperature sensors were put and taped. After putting the sensors, they dressed the equivital core body temperature belt. Afterward they dressed back up with socks, long sleeved trousers, a t-shirt and long sleeved shirt and all wires were put in one small handbag in order for them to feel more comfortable and protect the wires from braking. The equipment was turned on and the recording started for at least 20 minutes before they entered the climatic chamber. Afterward they sat and fulfil the general lifestyle questionnaire and the experimental protocol was explained to them. Ten minutes before entering the climatic chamber, their blood pressure was measured for three consecutive times with a pause between measurements of 15 seconds. The mean value of the systolic and diastolic pressure as the heart rate was recorded. Afterward they fulfilled the thermal sensation questionnaire. Five minutes before entering the climatic chamber they wore above all mentioned clothes the severe cold protective trousers, jacked with a hood, boots and gloves, leaving opened just the part of their eyes, cheek and nose. Finally they entered the climatic chamber.

4.2.3 In the climatic chamber

When entered the climatic chamber, they first turned on the speakers, as the music was provided in order to facilitate this one hour of exposure and activities. Afterward they followed the 20 minutes experimental protocol which was repeated for three consecutive times, except for the last time the protocol was finished with the thermal sensation questionnaire.

The researcher regulated the time of the experimental protocol, and when needed speed up or slow down the volunteers activities in order to have each of the experimental protocol phases conducted during 20 minutes, and the whole protocol finished in 60 minutes.

4.2.4 After the 60 minutes exposure period

When the volunteer exit the climatic chamber, he first undressed the cold protective jacket, trousers and boots. He sat on a chair and his blood pressure was measured. Afterward, 5 min after the cold exposure he answered the thermal sensation questionnaire, which he also answered 20 min, 40 min and 60 min after the exposure (in the recovery period). He was not allowed to drink anything, go to the toilet or walk around till one hour of the recovery period has passed. Then the skin and core temperature recordings were stopped, he was undressed, the equipment was removed and his body weight was measured again. At the end, all equipment were cleaned, recharged and all data were saved as a backup on a USB pen drive.

4.3 Selected equipment and questionnaires

Non-intrusive and intrusive equipment as ISO questionnaires were used in both laboratory and industrial experiments.

4.3.1 Climatic chamber

The climatic chamber Fitoclima 25000EC20 was used only in laboratory experiments. It was built according the rules and directives of the European Commission, regarding the requirements of health and safety. The climatic chamber had the ability to simulate exposure to different thermal environment conditions with air temperatures from -20ºC to +50ºC and relative humidity from 30% to 98% and equipped with CO_2 and O_2 sensors (Aralab 2010). The layout is illustrated in the figure 3.

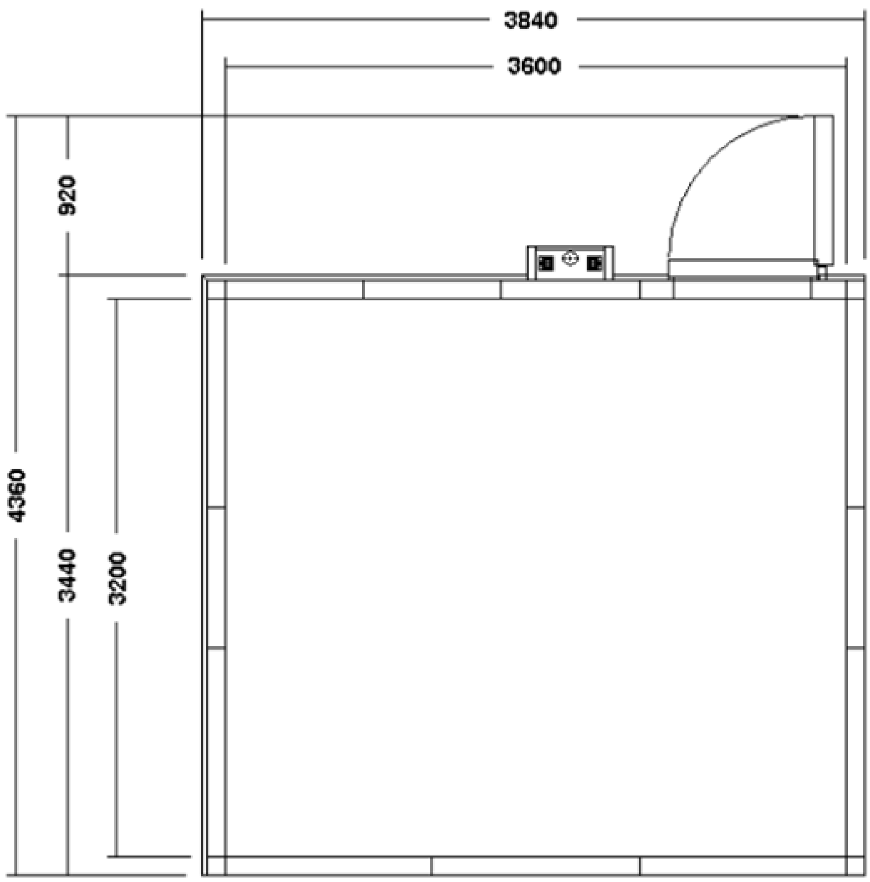

Figure 3 - The ground plan of the climatic chamber with dimensions in millimeters of the FITOCLIMA 25000 EC20 climatic chamber according to the manual (ARALAB 2010).

4.3.2 Skin temperature sensors

The skin temperature was measured using skin temperature sensors as illustrated in figure 4.

Figure 4 – The skin bioplux equipment.

The skin temperature sensors were put according to ISO 9886 (ISO 9886 2004) as illustrated in the figure 5, on 8 measuring points: forehead (Sk8), right arm in upper location (Sk7), right scapula (Sk6), left upper chest (Sk5), left arm in lower location (Sk4), left hand (Sk3), right anterior thigh (Sk2) and left calf (Sk1).

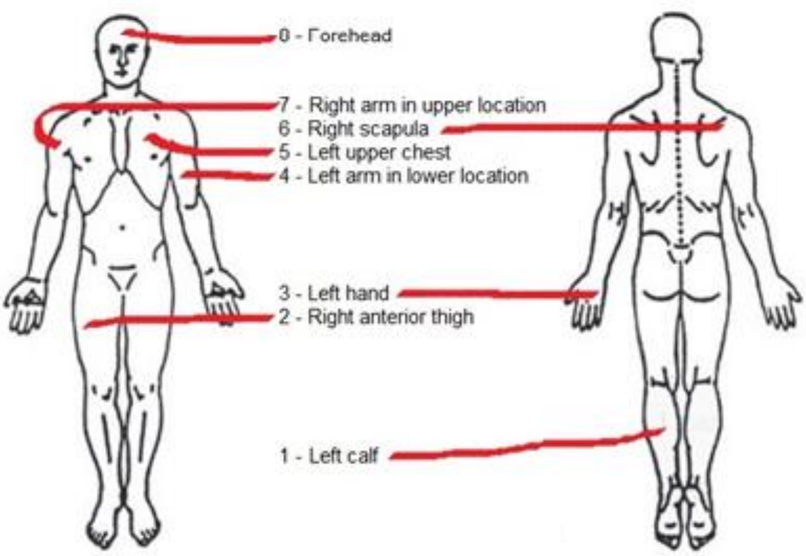

Figure 5 - Measuring with skin temperature sensors according to ISO 9886 (ISO 9886 2004).

4.3.3 Core temperature capsule

The intrusive core body temperature pill was used in all experiments. The core body temperature was found to be one of the most important parameters to monitor in order to reduce thr risk of health problems while exposed to cold temperatures. As well, it was essential when studying the influence of cold thermal environment on task performance. Ingestible thermal sensors (STI) allowed measurements of core body temperature, and was applied by researchers in several studies (with athletes, students and military in both laboratory and real conditions), validated by different authors and approved by ethics committees of their respective organizations. These ingestible pill sensors with dimensions of 8.7 mm by diameter and 23 mm by length, were already approved by the Ethical Committee of the University of Porto for the project named "*Influência do Ambiente Térmico na resposta cognitiva em Atividades Sedentárias*", approval number: 04/CEUP/2012; and re-approved for the project "Influence of severe cold thermal environment on task performance", approval number: 06/CEUP/2015. Ingestible pill sensor for measuring core body temperature (thermometer telemetry capsule) were swallowed with water for at least 5 hours before each test (normally before going to sleep); travelled along the digestive tract harmlessly, and leaving naturally within 24 to 72 hours. The sensors began to transmit one minute after the activation has been made by the external monitor, sending details every 15 seconds to a monitor EQ02 Life Monitor - Electronics Sensor Module (SEM), which transmits the data via Bluetooth. The details were sent to the telemetry recording system with an accuracy of +/- 0.01°C (Respironics; Mini Mitter; VitalSense 2006). The core body temperature pill with its belt for recording core temperature data, heart rate, blood pressure and respiratory frequency were showed in the figures 6, 7 and 8.

Figure 6 - The core body temperature equipment.

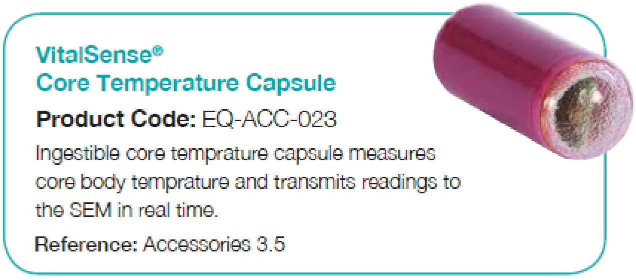

Figure 7 - The core body temperature pill (Equivital 2014).

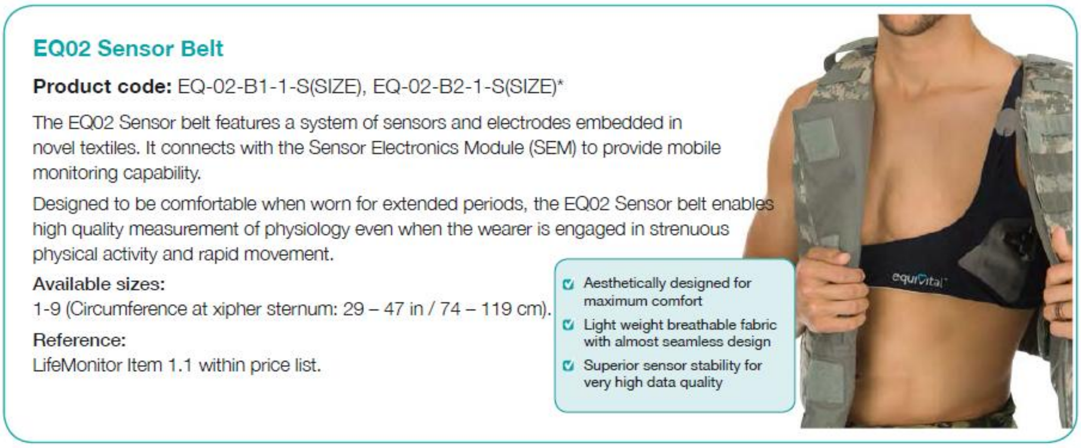

Figure 8 - The Equivital belt (Equivital 2014).

4.3.4 Blood pressure equipment

The blood pressure was measured in both experiments OMRON M10-IT Intellisense Upper Arm Blood Pressure Monitor, illustrated in the figure 9.

Figure 9 – The blood pressure Omron equipment.

4.3.5 Cold work health questionnaire

The Cold work health questionnaire was used in both experiments. The questionnaire illustrated in the final appendix was based on the Annex D of the ISO 15743:2008 with a usage of the original English version for the English speaking subjects in the laboratory experiments, and translated to Brazilian Portuguese for the subjects in the industry.

4.3.6 Thermal sensation questionnaire

The Thermal sensation questionnaire was used in all experiments. The questionnaire illustrated in the final appendix was based on the Annex B of the ISO 10551:1995 with a usage of the original English version for the English speaking subjects in the laboratory experiments, and translated to Brazilian Portuguese for industrial experiments held in Brazil.

4.3.7 Clothing

In the laboratory experiments, when exposed to severe cold, subjects wore special cold protective equipment (jacket with a hood, trousers, boots and gloves above their normal clothing (socks, underpants, t-shirt, trousers, thinly long-sleeved shirt), and when exposed to comfort they wore just normal clothing (sneakers, socks, underpants, t-shirt, shots). In the industrial experiments, maximal clothes that the subjects could were not defined, but didn't vary too much among the subjects. The subjects wore special cold protective equipment (jacket with a hood, trousers, boots), and gloves when entering the cold chamber and below their normal clothing (socks, underpants, t-shirt, trousers). Some subjects put their feet in plastic bags before wearing the boots.

4.3.8 Putting the equipment

The photos on how all the equipment was put and how volunteers were dressed, is illustrated in figures 10 and 11.

Figure 10 - The process of putting the equipment, industry.

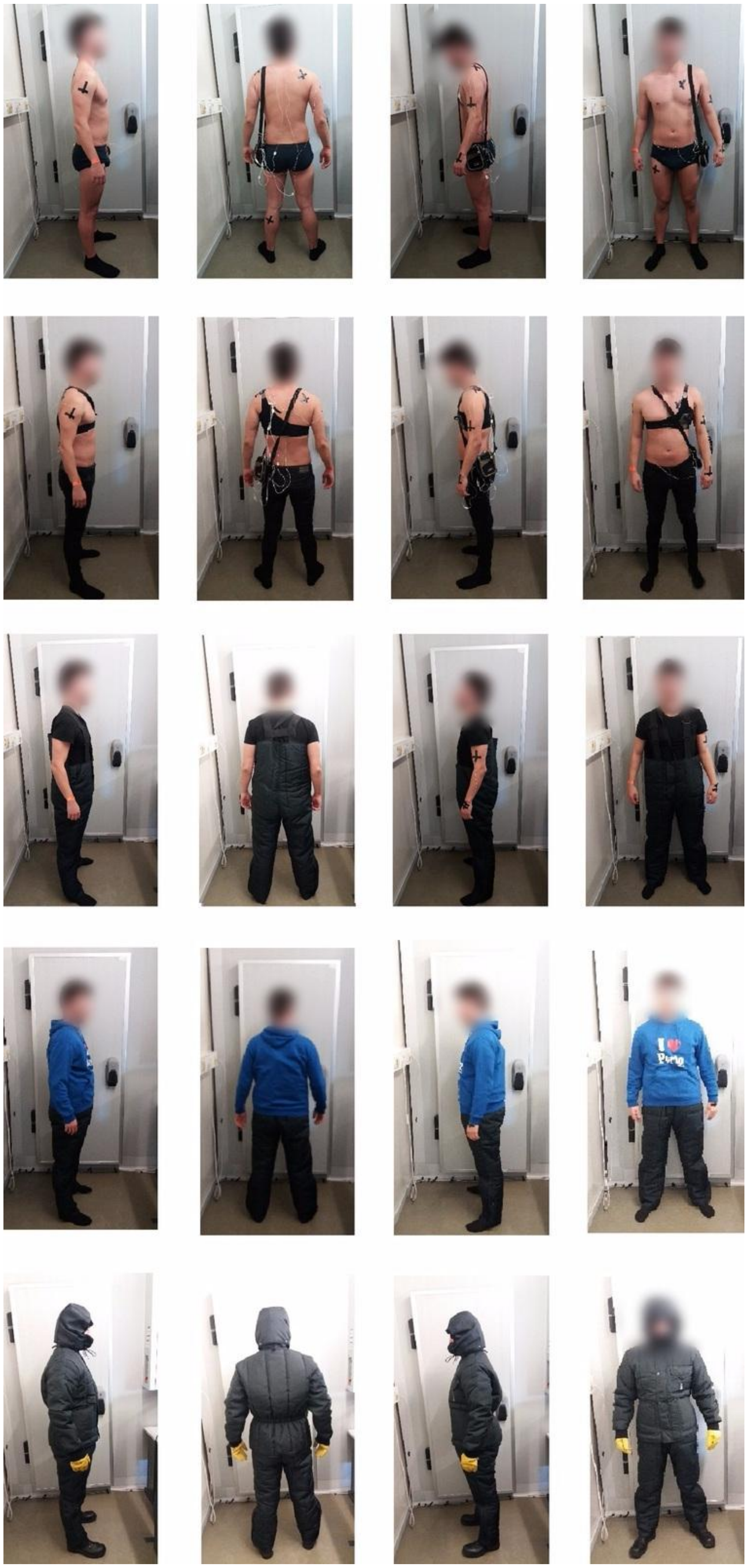

Figure 11 - The process of putting the equipment, laboratory.

4.4 Equipment Challenges

There were several challenges regarding the equipment used in the experiments. The climatic chamber was always working on its limits. Therefore there was a need to conduct tests on the working of the climatic chamber at -20°C, which is illustrated in the figure 12.

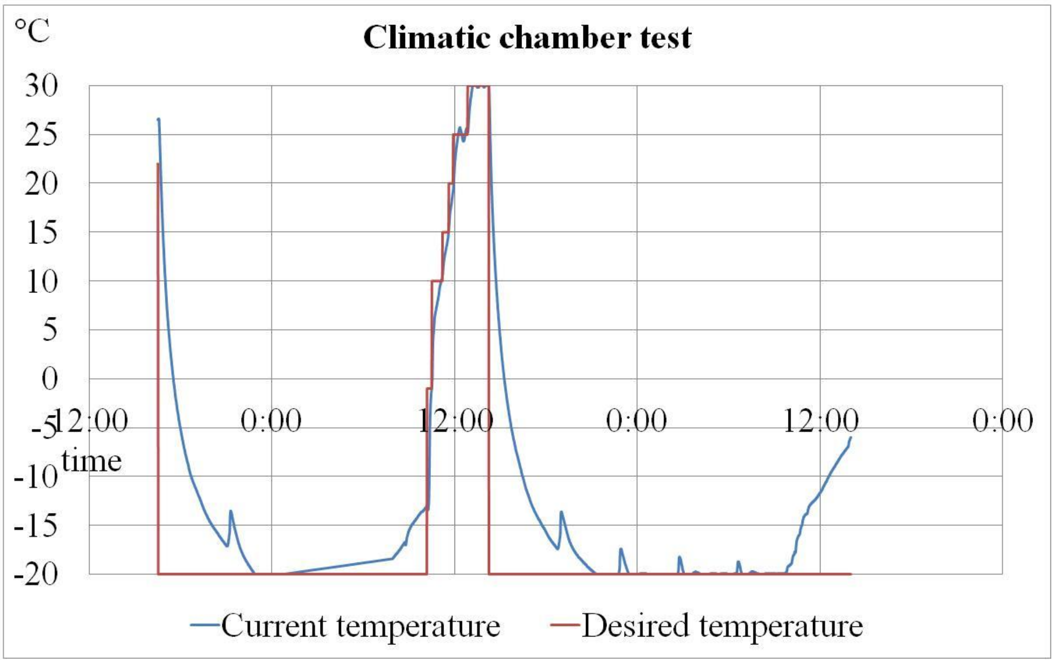

Figure 12 – The climatic chamber test.

It was found out that the climatic chamber took 6h 20 minutes to come from laboratory comfort temperature to -20°C, and that once achieved the desired temperature it has cycles of oscillations before it stabilize at -20°C. Further on, when the chamber doors would open the humidity would enter the chamber and freeze, as when volunteers were inside, they would produce humidity by breathing. This would further on cause the chamber to have more ice inside and function with greater effort and less efficiency. As illustrated in the figure 12, the test was chamber test defrosting was first put to -1°C, Rh turned off, afterward 10°C and 30% Rh, 15°C and 30% Rh, 20°C and 30% Rh, 25°C and 30% Rh, finally to put on 30°C and 30% Rh.

Later on, after each trial, it was decided to put the chamber defrosting, first 5°C and 30% Rh (and waiting the chamber to reach this conditions) afterward to 20°C and 30% Rh, finally to put on 30°C and 30% Rh. By this defrosting method, it was avoided the “rain” inside the chamber, the ice would slowly melt and humidity inside the chamber would be reduced. Afterward, some time was lost as the climatic chamber needed some reparations due to the malfunctioning of the system.

Further challenges were encountered with equivital and bioplux equipment as they both stopped working and needed reparation.

4.5 Data analysis

The references were searched through databases by using the institutional IP address of University of Porto federate credentials. References were managed using the Mendeley 1.15.3. The core body temperature was recorded by using the Equivital Manager and EqView professional programs. The skin body temperature was recorded by using the MonitorPlux program, later on to be processed by using a Matlab software program. When the Tcore was -1˚C in the gathered data, it was considered as outlier and therefore excluded from the graphics. The mean skin temperature was calculated using the weighting coefficients as suggested by ISO 9886:2004 (ISO 9886 2004). Statistical analysis was done by using excel statistical toolbox.

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5 INDUSTRIAL EXPERIMENTS

Influence of Cold Thermal Environment on Health, Thermal Sensation, Core and Skin temperatures in Packing Workers from a Frozen Food Processing Industry

ABSTRACT

In the fresh food industry the working activities are conducted in environmental temperatures from 0ºC to 10ºC, while in the frozen food industry usually are at temperatures below -20ºC. Both situations influence variations in core and skin body temperatures and affect the working performance, health and safety of the employees. The aim of this work is to evaluate the changes in thermal sensation throughout the day, the health of the workers and the influence of cold thermal environment on core and skin temperatures of packing workers in a frozen food processing industry. By using the thermal sensation questionnaire, cold work health questionnaire, thermometer telemetry capsule for measuring the intra-abdominal temperature and 8 skin temperature sensors a study was conducted during 11 working days. The lowest recorded hand temperature was 14.09 ºC, lowest forehead 18.55ºC, mean skin temperature had variations of 1.10 to 3.20 ºC along the working period and the mean body temperature on two occasions decreased below 35ºC. Highest and most frequent fluctuations were found in the hand and forehead skin temperature, small changes were found in mean skin temperature. The core temperature was found to increase due to vasoconstriction and higher physical exertion. The mean body temperature showed small changes along the time. Further studies should be conducted with a higher number of volunteers with same working activities and greater exposure to severe cold thermal environment.

KEYWORDS: Cold Exposure; Thermoregulation; Core Temperature; Skin Temperature; Thermal Sensation; Cold Work Health Questionnaire

5.1 Methodology

5.1.1 General data

The experiments were conducted in the cold packing sector of a frozen food processing factory on 27 acclimatized workers, 13 male (mean age±sd 25.20±5.43 years) and 14 female (mean age 34.40±5.00 years). Twenty-three of them fulfilled the thermal sensation questionnaire, twenty fulfilled the cold work health questionnaire, and five of them were selected to be fully monitored. All the documents used in the factory were in a Brazilian Portuguese version. The experiment was approved by the Ethics Committee of the University of Porto, approval number: 06/CEUP/2015.

In table 12 is shown the outside environmental conditions at near the industry location, gathered by the National Institute of Meteorology (INMET), station of meteorology of Macau, Rio Grande do Norte, Brazil.

Table 12 - Outside air temperature, relative humidity and air velocity data from the measuring days.

	09:00	**12:00**	**13:00**	**17:00**
Mean temperature±SD (°C)	25.10±0.84	29.30±1.48	29.80±2.13	29.70±2.00
Mean Relative Humidity±SD (%)	87.80±3.86	68.00±9.95	67.00±11.81	67.00±11.00
Mean Air velocity±SD (m/s²)	1.90±0.34	3.60±1.66	4.20±1.29	5.60±1.00

All workers usually spent their time in moderate cold thermal environment as illustrated in figure 13. Female workers conducting low physical repetitive work in a standing position (packing shrimps into 400 grams packages) as illustrated in figure 14, and male workers conducting moderate to heavy physical work (packing 400 grams packages into 20 kg packages, check the stored material, organize materials on pallets, separate materials from pallets, move pallets and heavy loads with forklifts, once a week breaking the ice on the floors in the severe cold chambers and do heavy liftings) as illustrated in figures 15, 16 and 17. The only male with low intensity work was the fully monitored volunteer number 1 which was the leader of logistics. The logistic leader delegates working tasks like to control, supervise and count the packages as illustrated in figure 1. He was the connection between offices and the stock. Although he does not do any heavy work his exposure to severe cold was higher than the other workers. Other volunteers selected to be fully monitored were male packing operators, spending mostly their time in moderate cold thermal environment, and several times per day storing frozen packages in the severe cold chambers. In the moderate cold sector the workers were exposed to temperatures below 18ºC, measured in a thermometer placed at 7 meters height.

Figure 13 – Moderate cold packing environment.

Figure 14 – Volunteer 4, female workers packing packages of 400 grams, and male workers packing into bigger boxes 10 kg inside the moderate cold sector.

Figure 15 – Volunteer 3, picking frozen packages of 400 grams from the frozen food chamber and then packing them into bigger boxes 20 kg.

Figure 16 – Volunteer 2, pushing 5 pots of ≈20 kg each from the frozen food chamber to moderate cold packing sector.

Figure 17 – Volunteer 2, pushing 5 pots of ≈20 kg each from the frozen food chamber to moderate cold packing sector.

Figure 18 – Volunteer 1 – logistics leader, first from the right, counting and reorganizing packages inside the frozen food chamber.

5.1.2 Thermal sensation questionnaire (TSQ)

The Thermal sensation questionnaire (based on the Annex B of the ISO 10551:199 (ISO 10551 1993)) was answered in total 100 times by 23 workers. Twelve males (mean age 25.5±5.52 years) answered 52 and eleven females (mean age 34.4±5.24) answered 48 questionnaires. It was conducted during three working days on 19/01/2016, 21/01/2016 and 26/01/2016 for workers from the cold packing sector. The answers were collected 4 times a day: around 08:00, at the beginning of the morning working period (fulfilled 34 times); around 12:00, at the end of the morning working period (fulfilled 13 times); around 13:30, at the beginning of the afternoon working period (fulfilled 25 times); and around 16:30, at the end of the afternoon working period (fulfilled 28 times). The number of questionnaires fulfilled on each day and part of the day varied, depending on the number of workers present at that time in the cold packing sector.

5.1.3 Cold work health questionnaire (CWHQ)

The Cold work health questionnaire (based on the Annex D of the ISO 15743:2008 (ISO 15743 2008)) was answered in total by 20 workers, one time by 10 male (mean age 25.7 ± 6.04 years) and 10 female (mean age 34.2 ± 4.91 years) workers from the cold packing sector. It was conducted during the same three working days as the TSQ. The questionnaire gives an overview of the workers self-evaluation on his/her cold sensitivity, cold urticaria, respiratory symptoms, cardiovascular symptoms, symptoms related to peripheral circulatory disturbances, symptoms related to white fingers, symptoms related to musculoskeletal system, local cold injuries and the effect of cold on performance.

5.1.4 Fully monitored workers

Five workers from the cold packing sector were chosen to be fully monitored during their working activities. Three of them were screened during 3 working days, while one during 2 working days. The trial with the fifth subject was interrupted during the first day as he was stressed with the equipment and didn't want to participate further. In total, a sample of 11 working periods was achieved. The mean age±sd of the successfully fully monitored workers was 29.00±6.32 years old, mean body height was 167.40±5.40 cm, mean weight of all 11 measuring days was 79.70±17.9 kg, mean body mass index (BMI) was 28.41±6.28 kg/m². The medical examination was conducted by the industrial medical doctor. All subjects were informed about the goals and risks of the experiments and signed the informed consent prior to participating. The subjects were examined and asked to drink the usual amount of coffee, tea, to avoid drinking alcohol for at least 12h before the test; not to eat spicy food at least 12h before the test; sleep normally before the test (about 8h); not conduct greater physical exertion than it is usual for the volunteer at least 1day before the test. All the subjects were non-smokers, didn't drink tea, alcohol, eat spicy food, were right handed and had a usual physical exertion the day before the trial was conducted. Every day before the trial, it was recorded what they ate in their previous meal, what time they ate, if they took some medicines, the time when they went to sleep and when they woke up, as well the number of hours they slept. All subjects had the same working period of 8 hours, the morning part from 07:30 till 11:30, the pause of 1 hour, and finally the afternoon part from 12:30 till 16:30 (working hours varying depending on the process situation). Daily exposure to SCE varied among workers depending on the activity from 1 to 31 minutes, with a maximal encountered interrupted exposure of 8 minutes.

The experiments were conducted during a normal working day, with the subjects performing the usual tasks being exposed to severe cold as usual and over the usual time period. The experiments were conducted with the usual industrial work of 8 hours at 16 to 18°C (measured at the height of 7 meters) and entering for several times to the frozen food chamber at air temperature of -25°C. Skin temperature (Tskin) was measured with bioplux skin temperature sensors. The sensors were put according to ISO 9886:2004 (ISO 9886 2004) on 8 measuring points: forehead (Sk8), right arm in upper location (Sk7), right scapula (Sk6), left upper chest (Sk5), left arm in lower location (Sk4), left hand (Sk3), right anterior thigh (Sk2) and left calf (Sk1). For measuring the core body temperature (Tcore) was used an Equivital Ingestible Pill Sensor (thermometer telemetry capsule) with dimensions of 8.7 mm by diameter and 23 mm by length. It was swallowed with water for at least 5 hours before each test (usually before going to sleep); travelled along the digestive tract harmlessly, and leaving naturally within 24 to 72 hours. The sensors began to transmit one minute after the capsule activation by the external monitor, sending details every 15 seconds to the EQ02 Life Monitor - Electronics Sensor Module (SEM), which transmits the data via Bluetooth. The SEM was transported in a belt, recording the data from core body temperature, chest skin temperature, heart rate, respiratory frequency and accelerometry (Acc). For the fully monitored workers, a codification was used for each volunteer “V01-D3-1”, where “V01” stands for volunteer number 1 (to each volunteer was given a code name), “D3” stands for the trial day of that specific volunteer, and the last number “1” stands for morning, while “2” for afternoon part of the trial.

In the table 13 are illustrated physical characteristics and lifestyle data from 4 fully monitored workers:

Table 13 – Detailed physical characteristics and lifestyle data from fully monitored workers.

Volunteer	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m²)	Coffee*	Last meal	Ate for the last meal*	Medications taking	Went to sleep and woke up	Sleeping hours	Working period
V1	21	161.0	88.60	34.20	NO	20:00	Sandwich	NO	23:00 – 06:00	7h	44h/d 6 d/w 17 m
			89.00	34.30		21:00	Cuscuz**		22:30 – 06:30	8h	
			92.40	35.60		19:30	Cuscuz**, bread, egg		22:30 – 06:40	8h 10’	
V2	27	174.0	100.20	33.10	YES	06:30	Chicken, bread, milk	NO	21:00 – 05:00	8h	44h/d 6 d/w 8 m
			101.20	33.40	YES	06:30	Bean soup	NO	21:40 – 05:30	7h 50’	
			98.00	32.40	NO	06:00	Milk with oatmeal	Headache pill	22:00 – 05:40	7h 40’	
V3	33	166.1	60.70	22.00	YES	06:30	Sandwich	NO	22:30 – 05:30	7h	44h/d 6 d/w 20 m
			61.30	22.20		06:20	Egg, bread		22:30 – 05:20	6h 50’	
			NA	NA							
V4	35	168.5	61.75	21.70	NO	06:20	Cuscuz**, milk	NO	00:00 – 06:00	6h	44h/d 6 d/w 16 m
			62.20	21.90			Cuscuz**, milk, egg		23:00 – 06:00	7h	
			61.60	21.70			Cuscuz**, sausage, milk		23:30 – 06:00	6h 30’	
Mean ± SD	29 ±6.3	167.4 ±5.4	77.81 ±19.74	27.75 ±6.82							15.25 ±5.12 months
			78.42 ±19.89	27.95 ±6.82							
			84.00 ±19.60	29.90 ±7.28							

* in the past 12 hours; **cuscus is a plain, steamed, cake-like cereal made with yellow, precooked corn meal

5.1.5 Clothing

The subjects wore the usual clothing (socks, underpants, t-shirt, trousers) and above it the cold protective clothing (jacket with a hood, trousers, boots), and sometimes gloves when entering the cold chamber. Some subjects put their feet in plastic bags before wearing the boots.

5.1.6 Data analysis

References were managed using the Mendeley 1.15.3. The core body temperature was recorded by using the Equivital Manager and EqView professional programs. The skin body temperature was recorded by using the MonitorPlux program, later on to be processed by using a Matlab 2014b software program. When the Tcore recorded value was -1˚C in the gathered data, it was considered as outlier and therefore excluded from the graphics. The mean skin temperature was calculated using the weighting coefficients as suggested by ISO 9886:2004 (ISO 9886 2004). Statistical analysis was done by using excel statistical toolbox.

5.2 Results

5.2.1 Thermal sensation questionnaire (TSQ)

The results of the TSQ are illustrated in the table 14. For the purpose of this study, 19 questionnaires from 19 workers were selected (9 males and 10 females), showing answers 3 times a day: at the beginning of the morning working period, at the beginning of the afternoon working period and at the end of the afternoon working period with a total of 57 questionnaires. Other questionnaires were excluded as the answers were gathered only in some day periods or the answers were from different day periods and different days. The answers 4 and 5 were excluded from this study as they seemed to be biased.

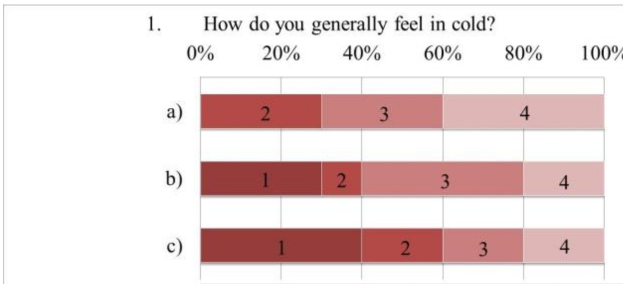
Table 14 – Thermal Sensation Questionnaire results.

	Question	**1. How do you feel at this precise moment: I am…(1)**			**2. How do you find this? (2)**			**3. At this moment, would you prefer to be? (3)**		
	Day period	**1**	**3**	**4**	**1**	**3**	**4**	**1**	**3**	**4**
Male volunteers	Mean	-2.22	-0.56	-1.33	-1.22	-0.33	-0.89	0.33	-0.11	-0.11
	±sd	1.64	2.51	2.12	0.83	0.50	1.27	0.71	1.05	1.27
Female volunteers	Mean	-2.20	-2.30	-2.10	-0.70	-0.50	-0.50	0.40	0.10	0.70
	±sd	1.14	1.42	0.99	0.82	0.71	0.71	0.70	1.10	1.06

(1) Scale from -4 to +4: -4 (very cold), -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm), +3 (hot), +4 (very hot);
(2) Scale from -4 to 0: -4 (extremely uncomfortable), -3 (very uncomfortable), -2 (uncomfortable), -1 (slightly uncomfortable, 0 (comfortable);
(3) Scale from -3 to +3: -3 (much cooler),-2 (cooler), -1 (slightly cooler), 0 (neutral/without change), +1 (slightly warmer), +2 (warmer), +3 (much warmer).

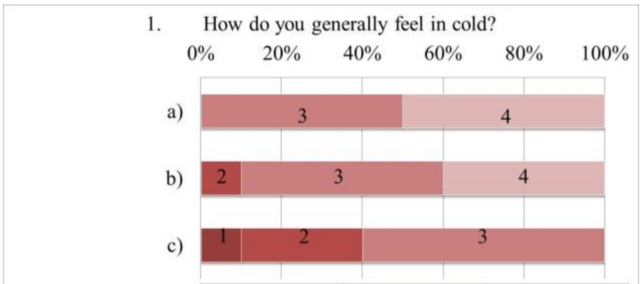
5.2.2 Cold work health questionnaire (CWHQ)

The results of the CWHQ are illustrated in the following figures. The results of the first question on cold sensitivity “How do you generally feel in cold?” with answers on whole body, fingers and toes, are illustrated in the figure 19 for male and figure 20 for female workers.



	c)	b)	a)
1 Very unpleasant	40,00%	30,00%	0,00%
2 Unpleasant	20,00%	10,00%	30,00%
3 Slighyly unpleasant	20,00%	40,00%	30,00%
4 Pleasant	20,00%	20,00%	40,00%

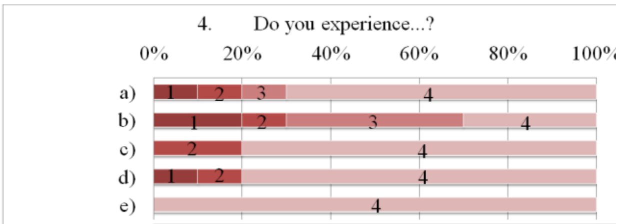
Figure 19 - Results for male workers on the question 1 “How do you generally feel in cold?” with answers regarding a) Whole body, b) Fingers, c) Toes.



	c)	b)	a)
1 Very unpleasant	10,00%	0,00%	0,00%
2 Unpleasant	30,00%	10,00%	0,00%
3 Slighyly unpleasant	60,00%	50,00%	50,00%
4 Pleasant	0,00%	40,00%	50,00%

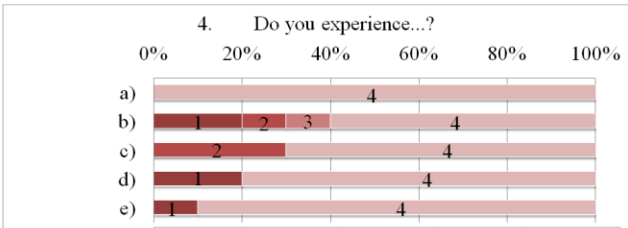
Figure 20 - Results for female workers on the question 1 “How do you generally feel in cold?” with answers regarding a) Whole body, b) Fingers, c) Toes.

The results of the fourth CWHQ question on respiratory symptoms “Do you experience...?” regarding shortness of breath, extended coughing or coughing fits, wheezing, increased excretion of mucus from the lungs and very profound rhinitis, are illustrated in the figure 21 for male and 22 for female workers.



	e)	d)	c)	b)	a)
1 In cold	0,00%	10,00%	0,00%	20,00%	10,00%
2 In warm	0,00%	10,00%	20,00%	10,00%	10,00%
3 In cold during exertion	0,00%	0,00%	0,00%	40,00%	10,00%
4 Not at all	100,00%	80,00%	80,00%	30,00%	70,00%

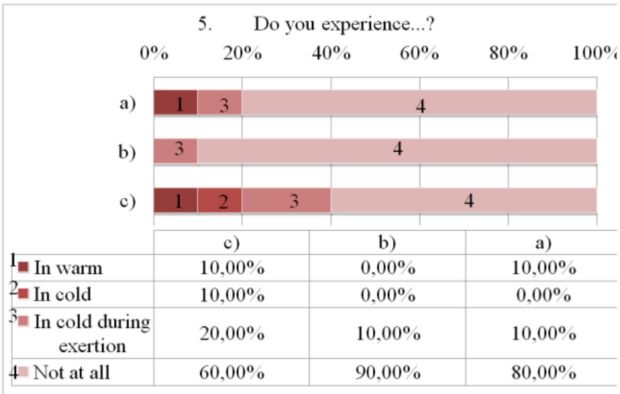
Figure 21 – Results for male workers on the question 4 “Do you experience...?” with answers regarding a)Shortness of breath?, b) Extended coughing or coughing fits?, c) Wheezing?, d) Increased excretion of mucus from the lungs?, e) Very profound rhinitis?



	e)	d)	c)	b)	a)
1 In cold	10,00%	20,00%	0,00%	20,00%	0,00%
2 In warm	0,00%	0,00%	30,00%	10,00%	0,00%
3 In cold during exertion	0,00%	0,00%	0,00%	10,00%	0,00%
4 Not at all	90,00%	80,00%	70,00%	60,00%	100,00%

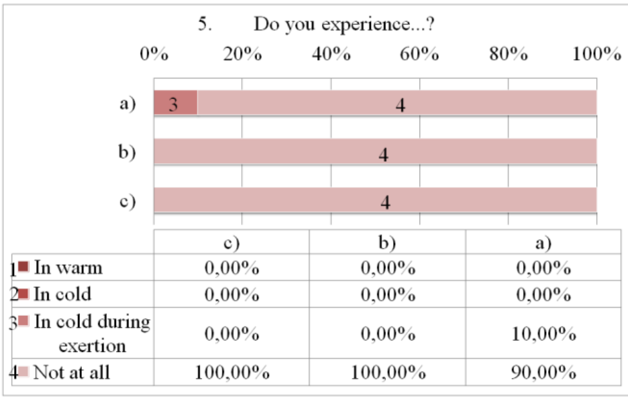
Figure 22 – Results for female workers on the question 4 “Do you experience...?” with answers regarding a)Shortness of breath?, b) Extended coughing or coughing fits?, c) Wheezing?, d) Increased excretion of mucus from the lungs?, e) Very profound rhinitis?

The results of the third CWHQ question on cardiovascular symptoms “Do you experience...?” with answers regarding chest pain, cardiac arrhythmias, high blood pressure, are illustrated in the figure 23 for male and 24 for female workers.



	c)	b)	a)
1 In warm	10,00%	0,00%	10,00%
2 In cold	10,00%	0,00%	0,00%
3 In cold during exertion	20,00%	10,00%	10,00%
4 Not at all	60,00%	90,00%	80,00%

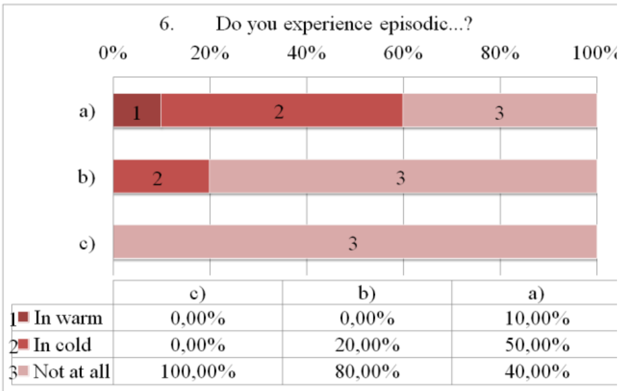
Figure 23 – Results for male workers on the question 5 “Do you experience...?” with answers regarding a) Chest pain?, b) Cardiac arrhythmias?, c) High blood pressure?



	c)	b)	a)
1 In warm	0,00%	0,00%	0,00%
2 In cold	0,00%	0,00%	0,00%
3 In cold during exertion	0,00%	0,00%	10,00%
4 Not at all	100,00%	100,00%	90,00%

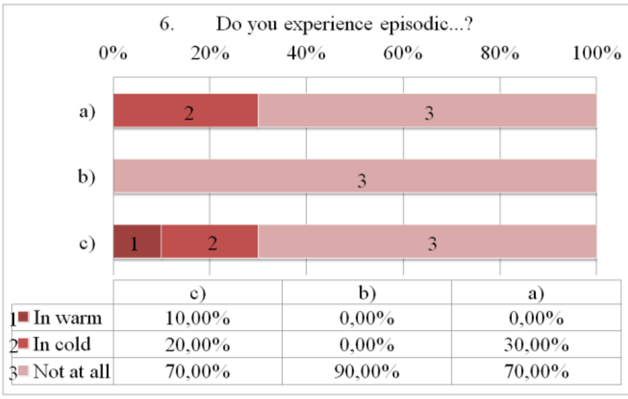
Figure 24 – Results for female workers on the question 5 “Do you experience...?” with answers regarding a) Chest pain?, b) Cardiac arrhythmias?, c) High blood pressure?

The results of the sixth CWHQ question on symptoms related to peripheral circulatory disturbances “Do you experience episodic...?” with answers regarding circulatory disturbances in hands and/or feet, blurring of vision, headache named migraine, are illustrated in the figure 25 for male and 26 for female workers.



	c)	b)	a)
1 In warm	0,00%	0,00%	10,00%
2 In cold	0,00%	20,00%	50,00%
3 Not at all	100,00%	80,00%	40,00%

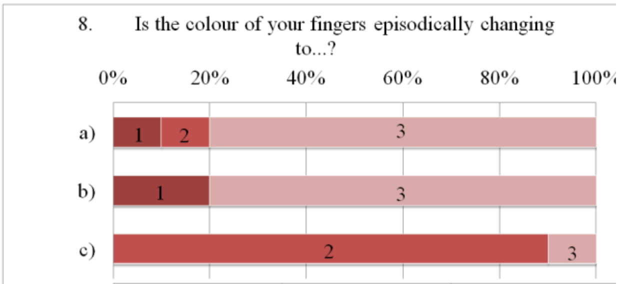
Figure 25 – Results for male workers on the question 6 “Do you experience episodic...?” with answers regarding a) Circulatory disturbances in hands and/or feet, b) Blurring of vision, c) Headache named migraine.



	c)	b)	a)
1 In warm	10,00%	0,00%	0,00%
2 In cold	20,00%	0,00%	30,00%
3 Not at all	70,00%	90,00%	70,00%

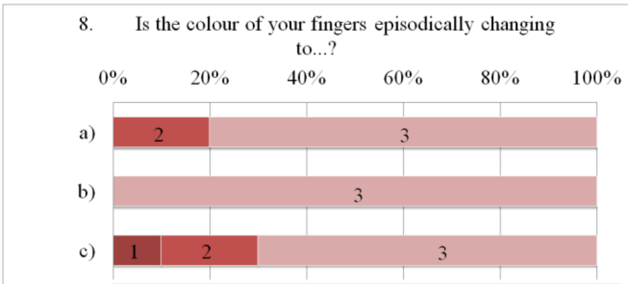
Figure 26 – Results for female workers on the question 6 “Do you experience episodic...?” with answers regarding a) Circulatory disturbances in hands and/or feet, b) Blurring of vision, c) Headache named migraine.

The results of the sixth CWHQ question on symptoms related to white fingers "Is the colour of your fingers episodically changing to...?" with answer options to white, blue and red/violet, are illustrated in the figure 27 for male and 28 for female workers.



	c)	b)	a)
1 In warm	0,00%	20,00%	10,00%
2 In cold	90,00%	0,00%	10,00%
3 Not at all	10,00%	80,00%	80,00%

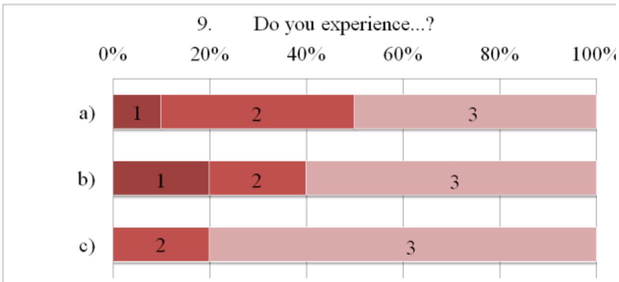
Figure 27 – Results for male workers on question 8:"Is the color of your fingers episodically changing to...?" with answers-options a) White, b) Blue, c) Red/violet.



	c)	b)	a)
1 In warm	10,00%	0,00%	0,00%
2 In cold	20,00%	0,00%	20,00%
3 Not at all	70,00%	100,00%	80,00%

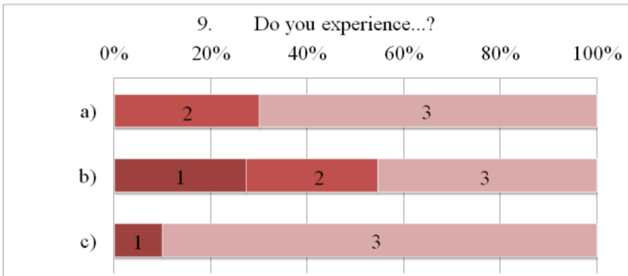
Figure 28 – Results for female workers on question 8:"Is the color of your fingers episodically changing to...?" with answers-options: a) White, b) Blue, c) Red/violet.

The results of the ninth CWHQ question on symptoms related to the musculoskeletal system "Do you experience...?" with answer regarding neck/shoulder or upper extremity pain, back or hip pain and pain in lower extremities, are illustrated in the figure 29 for male and 30 for female workers.



	c)	b)	a)
1 In warm	0,00%	20,00%	10,00%
2 In cold	20,00%	20,00%	40,00%
3 Not at all	80,00%	60,00%	50,00%

Figure 29 – Results for male workers on question 9 "Do you experience...?" with answers regarding a) Neck/shoulder or upper extremity pain, b) Back or hip pain, c) Pain in lower extremities.



	c)	b)	a)
1 In warm	10,00%	30,00%	0,00%
2 In cold	0,00%	30,00%	30,00%
3 Not at all	90,00%	50,00%	70,00%

Figure 30 – Results for female workers on question 9 "Do you experience...?" with answers regarding a) Neck/shoulder or upper extremity pain, b) Back or hip pain, c) Pain in lower extremities.

The results of the CWHQ question twelve, on effects of cold on performance How does cold affect the following factors of your performance during work?" with answer regarding concentration, motivation and musculoskeletal endurance, are illustrated in the figure 31 for male and 32 for female workers.

*P = performance **PD = performance decreased

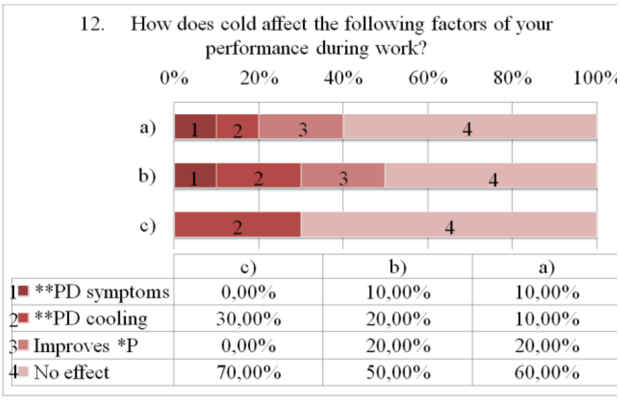


Figure 31 – Results for male workers on question 12 "How does cold affect the following factors of your performance during work?" with answers regarding a) Concentration, b) Motivation, c) Musculoskeletal endurance.

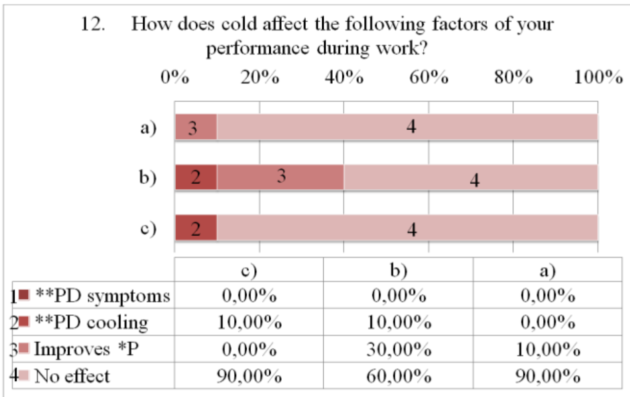


Figure 32 – Results for female workers on question 12 "How does cold affect the following factors of your performance during work?" with answers regarding a) Concentration, b) Motivation, c) Musculoskeletal endurance.

5.2.3 Fully monitored workers Tskin and Tcore temperature variations

In table 15 are presented the mean as well the minimum and maximum value of some of the main collected data of skin and core temperature. From this data can be highlighted the values bellow 35ºC for mean body temperature.

Table 15 - Mean, minimal and maximal temperatures.

		Left hand	**Forehead**	**Core temperature**	**Mean skin temperature**	**Mean body temperature**
V01_D1_1 temp. (°C)	mean±SD	30.13±1.67	33.79±0.67	37.49±0.10	32.58±0.29	36.02±0.10
	min	18.60	31.54	37.31	31.56	35.72
	max	32.56	34.69	37.83	33.27	36.27
V01_D1_2 temp. (°C)	mean±SD	28.81±1.96	32.68±1.39	37.62±0.06	32.32±0.54	36.03±0.16
	min	20.54	26.25	37.50	30.23	35.42
	max	32.15	34.79	37.75	33.35	36.33
V01_D2_1 temp. (°C)	mean±SD	30.58±1.86	33.91±0.63	37.13±0.08	32.98±0.41	35.89±0.12
	min	25.11	31.35	36.88	31.56	35.47
	max	33.42	35.03	37.26	33.72	36.18
V01_D3_1 temp. (°C)	mean±SD	23.09±1.56	29.57±1.05	37.31±0.04	30.13±0.27	35.15±0.08
	min	18.33	26.05	37.24	29.41	34.98
	max	26.57	30.74	37.41	30.54	35.29
V01_D3_2 temp. (°C)	mean±SD	25.62±2.92	32.21±1.00	37.63±0.06	31.62±0.67	35.83±0.21
	min	14.09	28.63	37.55	30.01	35.29
	max	30.55	34.18	37.73	33.24	36.32
V02_D1_1 temp. (°C)	mean±SD	28.03±3.47	33.95±0.89	37.67±0.16	31.65±0.46	35.86±0.15
	min	18.55	29.67	37.36	30.25	35.49
	max	33.64	34.94	37.91	33.01	36.15
V02_D1_2 temp. (°C)	mean±SD	29.89±2.68	32.74±1.17	37.57±0.04	31.79±0.63	35.83±0.18
	min	17.96	28.22	37.46	30.49	35.48
	max	34.64	35.41	37.64	33.33	36.26
V02_D2_1 temp. (°C)	mean±SD	26.71±3.77	29.56±2.98	37.59±0.11	31.14±1.28	35.65±0.44
	min	14.46	18.55	37.44	29.08	34.94
	max	32.80	35.01	37.81	34.22	36.59
V03_D1_1 temp. (°C)	mean±SD	29.57±0.85	32.59±0.75	37.51±0.12	31.87±0.52	35.82±0.17
	min	26.59	29.69	37.35	30.62	35.41
	max	30.85	34.00	37.77	33.78	36.35
V03_D2_1 temp. (°C)	mean±SD	29.24±1.29	33.21±0.62	37.32±0.20	32.78±0.57	35.95±0.20
	min	25.56	30.09	36.87	30.77	35.58
	max	31.61	34.03	37.76	33.72	36.39
V03_D2_2 temp. (°C)	mean±SD	29.21±1.58	33.97±0.79	37.59±0.13	33.32±0.56	36.31±0.13
	min	25.49	31.63	37.37	31.61	35.89
	max	32.10	35.36	37.88	34.02	36.54
V04_D1_2 temp. (°C)	mean±SD	32.40±1.05	34.02±0.34	36.99±0.17	33.09±0.55	35.82±0.19
	min	27.88	32.20	36.55	30.89	35.30
	max	33.71	34.79	37.28	34.08	36.18
V04_D3_1 temp. (°C)	mean±SD	24.18±2.72	33.53±0.40	36.92±0.08	33.58±0.29	35.92±0.07
	min	18.38	31.87	36.74	32.63	35.70
	max	28.20	34.64	37.14	34.05	36.09
V04_D3_2 temp. (°C)	mean±SD	30.72±1.26	34.61±0.60	37.06±0.06	33.59±0.49	36.02±0.13
	min	27.36	32.44	36.96	32.05	35.63
	max	32.13	35.13	37.22	34.29	36.26

In the figures 33, 34, 35 and 36 are illustrated industrial results on skin and core temperature data recorded for volunteer 1 on day 1 during morning and in figures 37, 38, 39 and 40 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

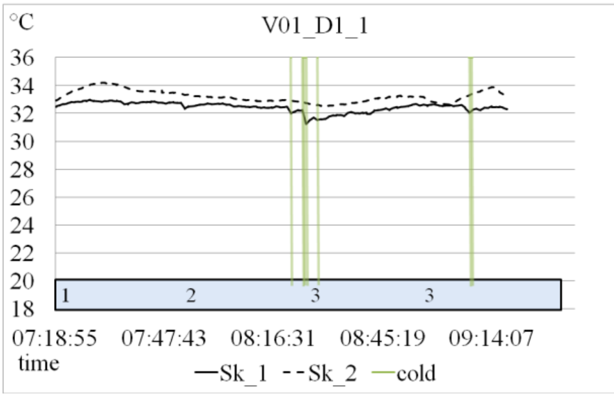


Figure 33 – Results for the volunteer 1 on day 1 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

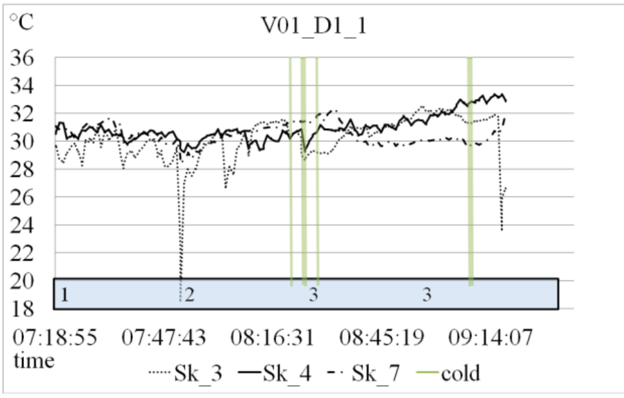


Figure 34 – Results for the volunteer 1 on day 1 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

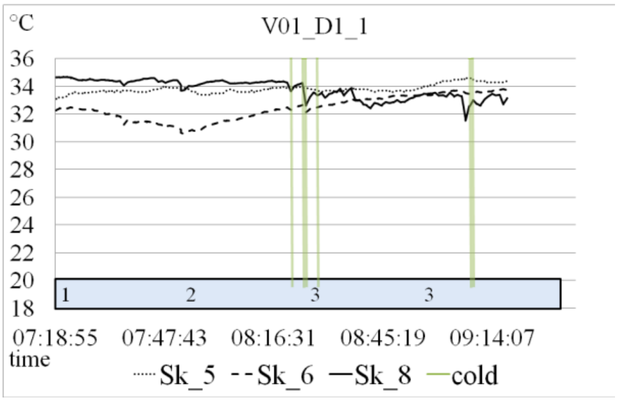


Figure 35 – Results for the volunteer 1 on day 1 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

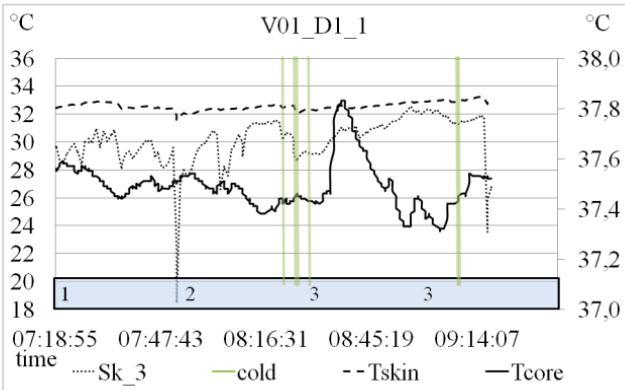


Figure 36 – Results for the volunteer 1 on day 1 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈32.0 to 34.0°C, with lowest left calf (Sk_1) recorded value during SCE exposure. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18 to 32°C. The highest hand skin temperature decrease is illustrated on figure 34 and 36, at ≈07:47, occurred due to barehanded touching the frozen food package. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈29.0 to 33.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈33.0 to 35.0°C, right scapula (Sk_6) from ≈30.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈32.0 to 35.0°C, slowly decreasing from the start till the end of the working period. The core temperature had variations from ≈37.1 to 37.8°C.

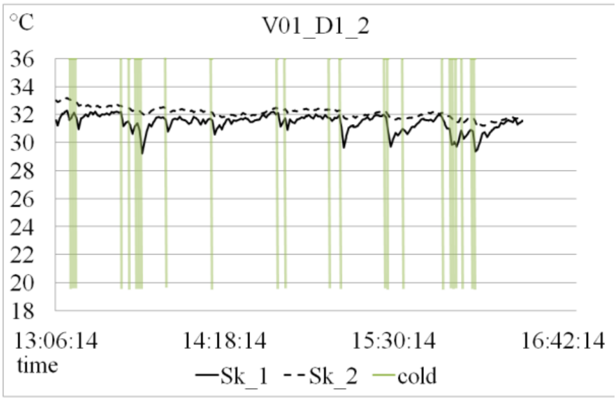


Figure 37 – Results for the volunteer 1 on day 1 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

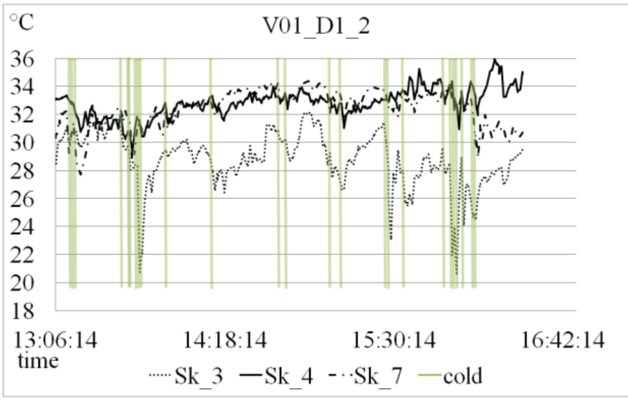


Figure 38 – Results for the volunteer 1 on day 1 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

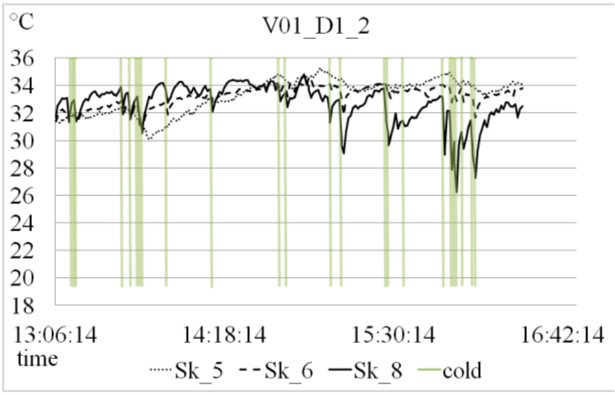


Figure 39 – Results for the volunteer 1 on day 1 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

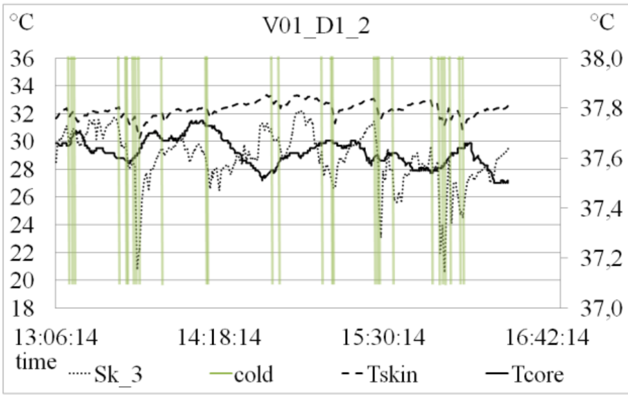


Figure 40 – Results for the volunteer 1 on day 1 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈29.0 to 33.0°C, with lowest left calf (Sk_1) recorded value after SCE exposure. Left hand skin temperature (Sk_3) variations were highest, varying from ≈21.0 to 32.0°C. The highest hand skin temperature decreases occurred during exposure to SCE. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈28.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈30.0 to 35.0°C, right scapula (Sk_6) from ≈32.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈26.0 to 34.0°C, where highest decreases occurred during exposure to SCE. The core temperature had variations from ≈37.5 to 37.7°C, with increases mostly occurring during exposure to SCE.

In the figures 41, 42, 43 and 44 are illustrated industrial results on skin and core temperature data recorded for volunteer 1 on day 2 during morning and in figures 45, 46, 47 and 48 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas, while periods within the severe hot thermal environment (outside) are marked with vertical purple shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

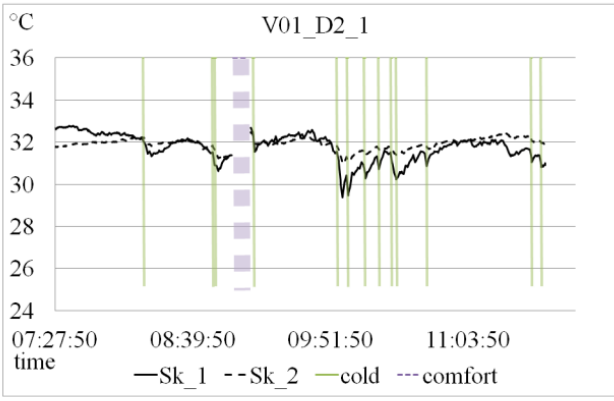


Figure 41 – Results for the volunteer 1 on day 2 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

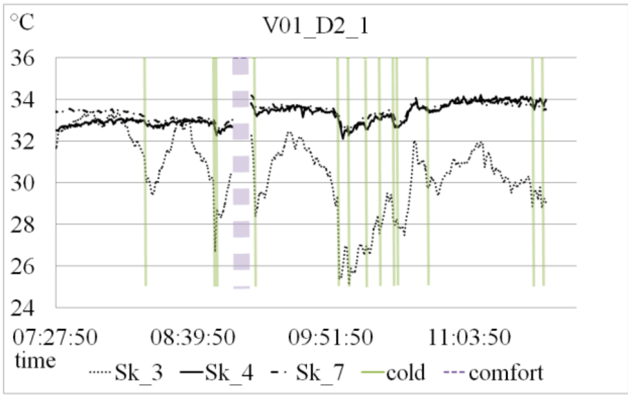


Figure 42 – Results for the volunteer 1 on day 2 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

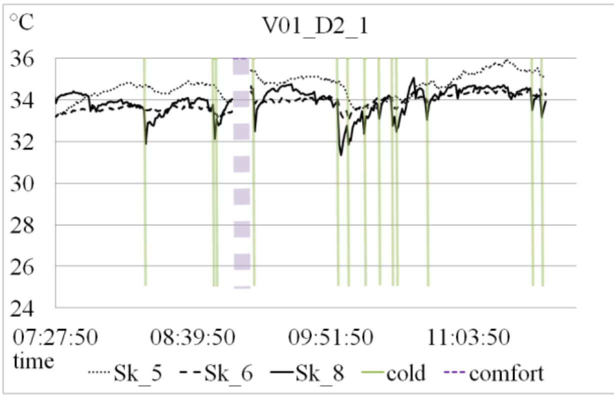


Figure 43 – Results for the volunteer 1 on day 2 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

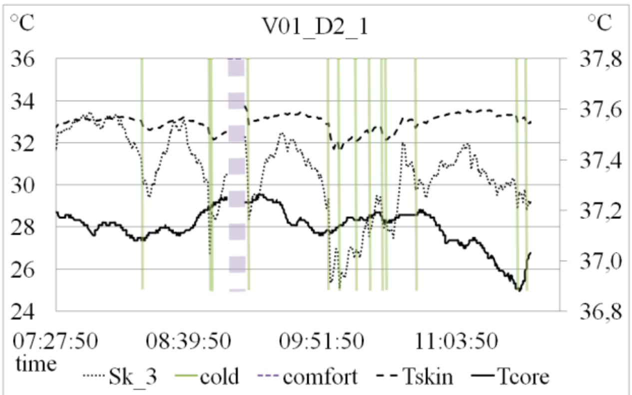


Figure 44 – Results for the volunteer 1 on day 2 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈29.5 to 33.0°C, with lowest left calf (Sk_1) recorded value after SCE exposure. Left hand skin temperature (Sk_3) variations were highest, varying from ≈25.0 to 33.0°C. The highest hand skin temperature decreases occurred during exposure to SCE. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈32.0 to 34.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈33.0 to 36.0°C, right scapula (Sk_6) from ≈33.0 to 34.5°C and forehead skin temperature (Sk_8) from ≈31.5 to 35°C, slowly decreasing from the start till the end of the working period. The core temperature had variations from ≈36.9 to 37.3°C.

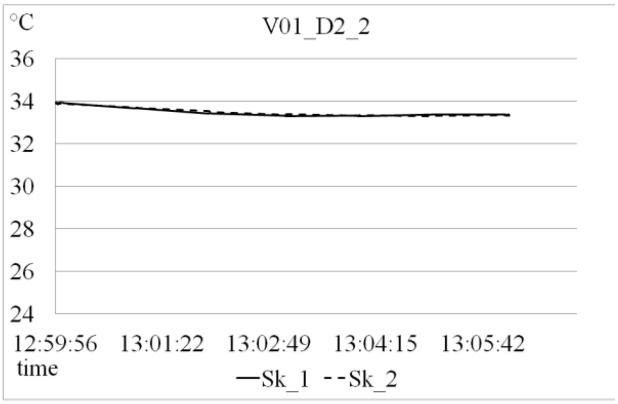


Figure 45 – Results for the volunteer 1 on day 2 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

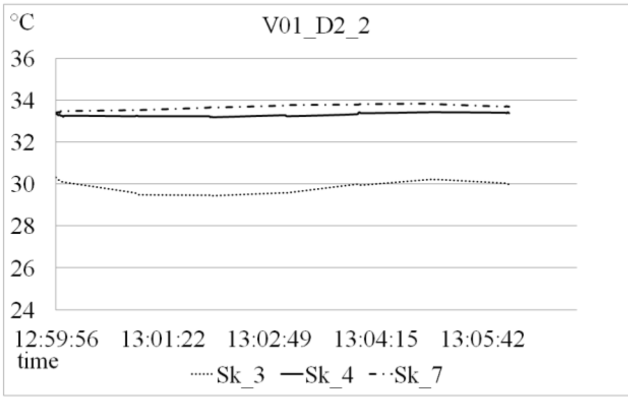


Figure 46 – Results for the volunteer 1 on day 2 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

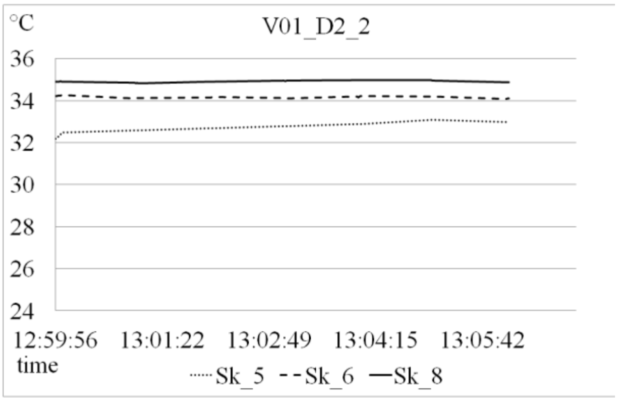


Figure 47 – Results for the volunteer 1 on day 2 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

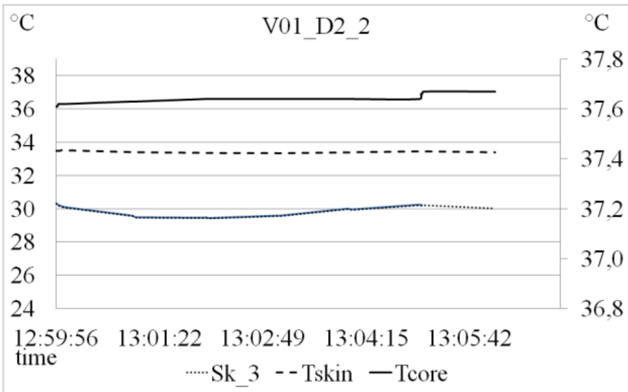


Figure 48 – Results for the volunteer 1 on day 2 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈33.0 to 34.0°C, left hand skin temperature (Sk_3) variations from ≈29.0 to 30.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈33.0 to 34.0°C. The chest skin temperature (Sk_5) had variations from ≈32.0 to 33.0°C, right scapula (Sk_6) ≈34.0 °C and forehead skin temperature (Sk_8) from ≈35.0°C. The core temperature had variations ≈37.7°C.

In the figures 49, 50, 51 and 52 are illustrated industrial results on skin and core temperature data recorded for volunteer 1 on day 3 during morning and in figures 53, 54, 55 and 56 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

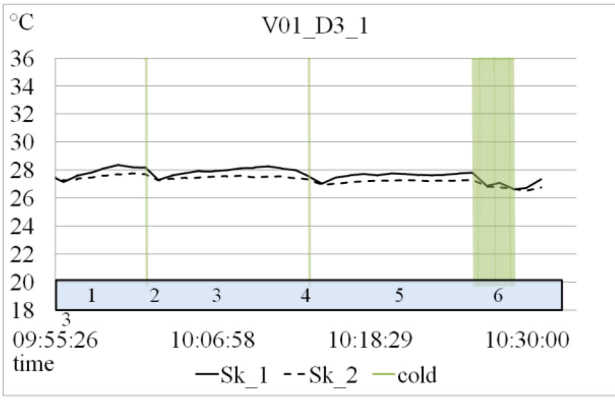


Figure 49 – Results for the volunteer 1 on day 3 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

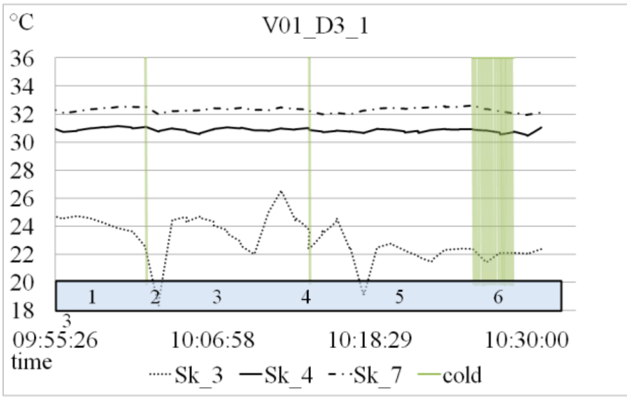


Figure 50 – Results for the volunteer 1 on day 3 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

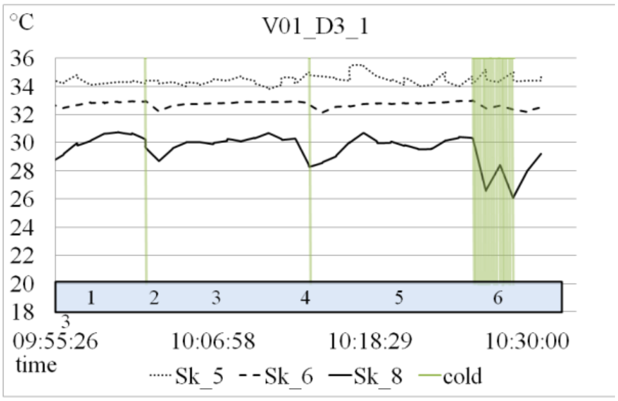


Figure 51 – Results for the volunteer 1 on day 3 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

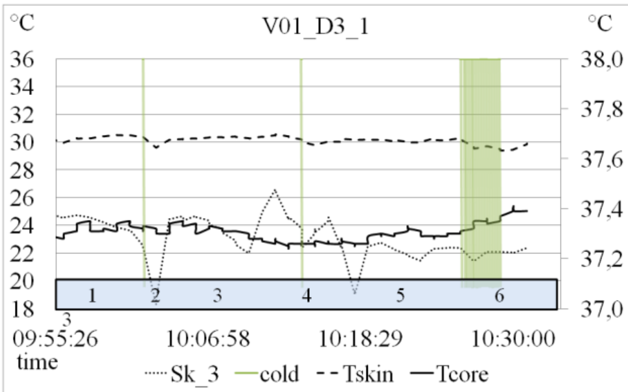


Figure 52 – Results for the volunteer 1 on day 3 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈27.0 to 28.0°C, with lowest recorded values after SCE exposure. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18.0 to 27.0°C. The highest hand skin temperature decreases didn’t occurred during exposure to SCE. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈31.0 to 33.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈34.0 to 35.5°C, right scapula (Sk_6) from ≈32.0 to 33.0°C and forehead skin temperature (Sk_8) from ≈26.0 to 31.0°C, with highest decrease in the last and longest SCE exposure. The core temperature had variations from ≈37.2 to 37.4°C, with highest increase occurring during the last and longest SCE exposure.

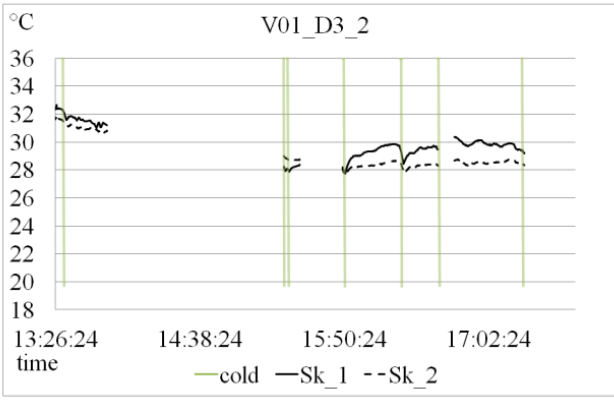


Figure 53 – Results for the volunteer 1 on day 3 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

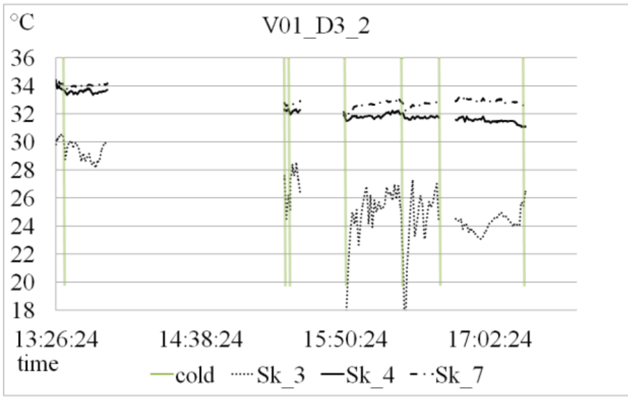


Figure 54 – Results for the volunteer 1 on day 3 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

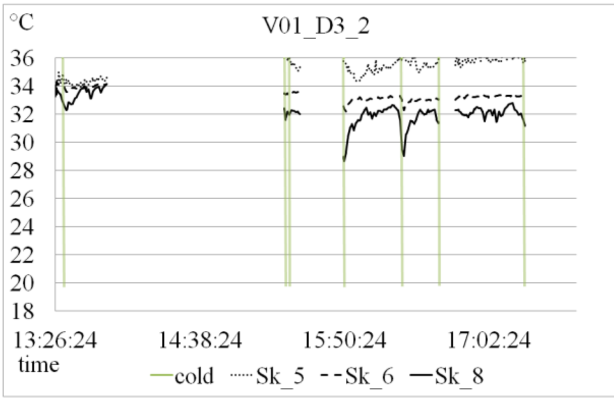


Figure 55 – Results for the volunteer 1 on day 3 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

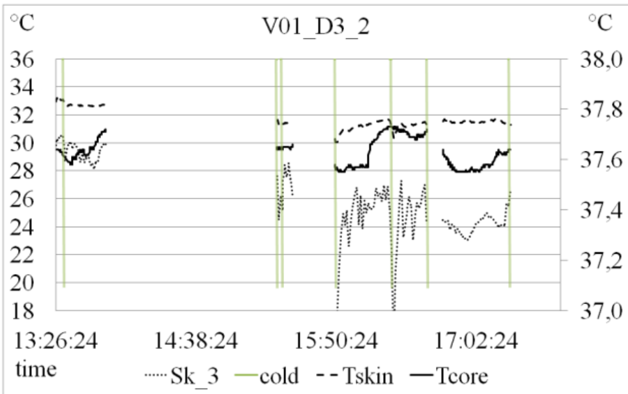


Figure 56 – Results for the volunteer 1 on day 3 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 33.0°C, with lowest left calf (Sk_1) recorded value after SCE exposures. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18.0 to 30.0°C. The highest hand skin temperature decreases occurred after exposures to SCE. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈31.0 to 34.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈34.0 to 36.0°C, right scapula (Sk_6) from ≈32.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈29.0 to 34.0°C, where highest decreases occurred during exposure to SCE. The core temperature had variations from ≈37.5 to 37.8°C.

In the figures 57, 58, 59 and 60 are illustrated industrial results on skin and core temperature data recorded for volunteer 2 on day 1 during morning and in figures 61, 62, 63 and 64 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

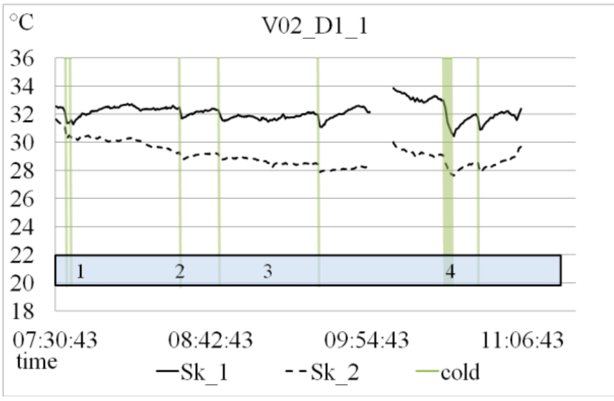


Figure 57 – Results for the volunteer 2 on day 1 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

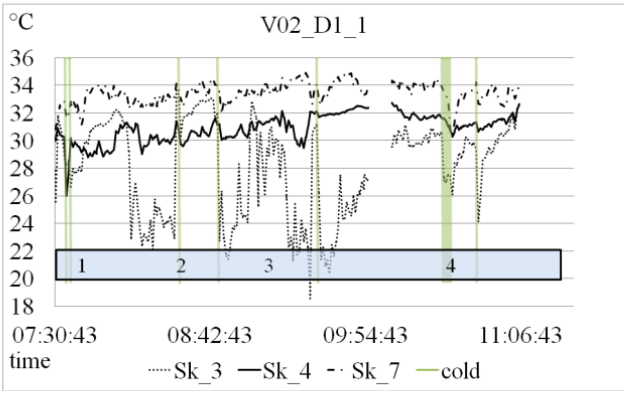


Figure 58 – Results for the volunteer 2 on day 1 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

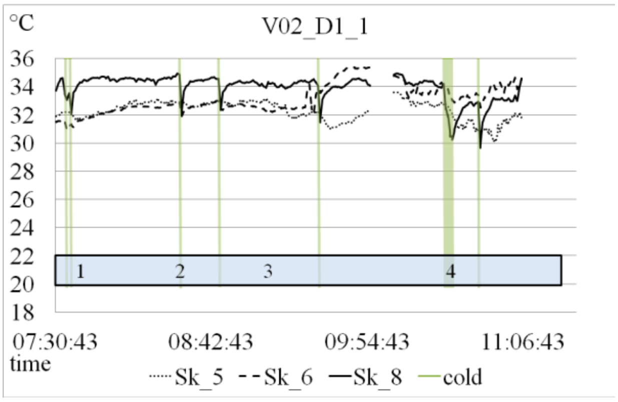


Figure 59 – Results for the volunteer 2 on day 1 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

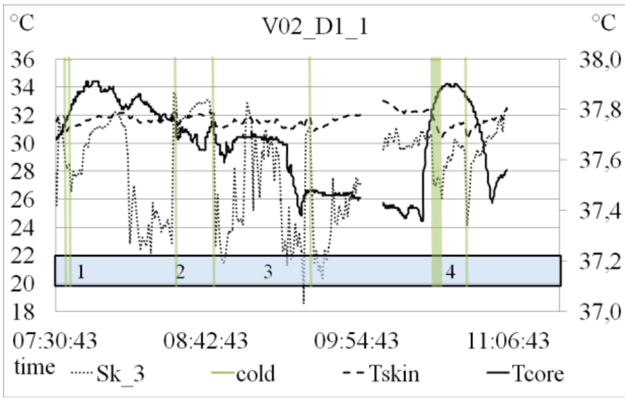


Figure 60 – Results for the volunteer 2 on day 1 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 34.0°C, with lowest recorded values after SCE exposure. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18.0 to 33.0°C. The highest hand skin temperature decreases occurred after SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈26.0 to 35.0°C. The chest skin temperature (Sk_5) had variations from ≈30.0 to 34.0°C, right scapula (Sk_6) from ≈31.0 to 35.5°C and forehead skin temperature (Sk_8) from ≈30.0 to 35°C, with highest decrease after SCE exposures. The core temperature had variations from ≈37.3 to 37.9°C.

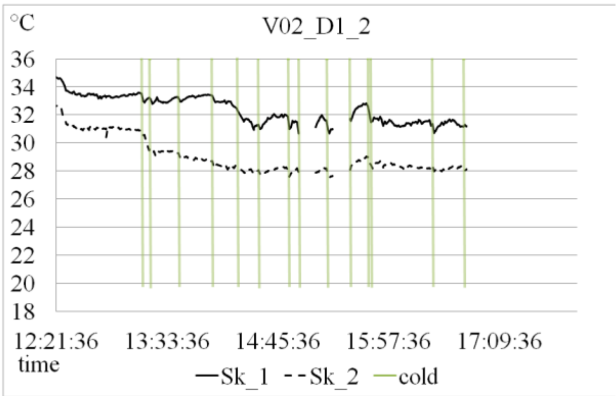


Figure 61 – Results for the volunteer 2 on day 1 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

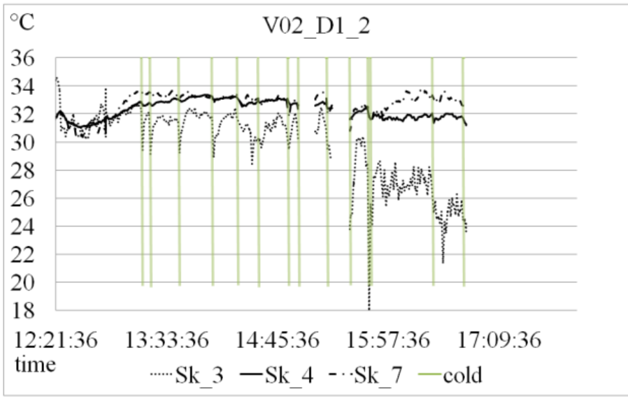


Figure 62 – Results for the volunteer 2 on day 1 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

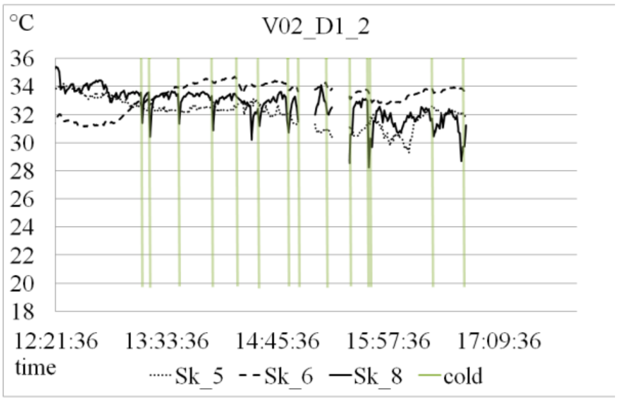


Figure 63 – Results for the volunteer 2 on day 1 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

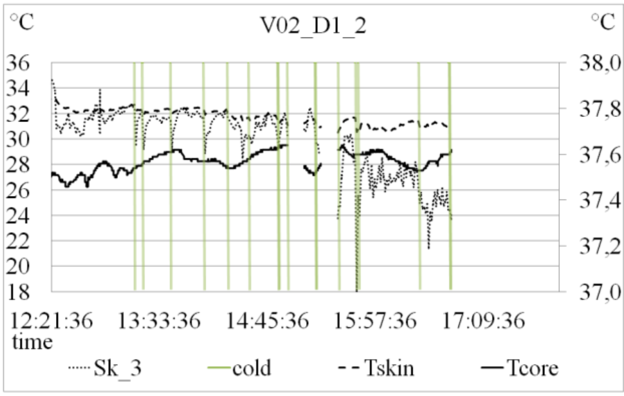


Figure 64 – Results for the volunteer 2 on day 1 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 35.0°C, with lowest recorded values after SCE exposures. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18.0 to 34.5°C. The highest hand skin temperature decreases occurred after SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈30.0 to 34.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈29.5 to 34.0°C, right scapula (Sk_6) from ≈31.0 to 34.5°C and forehead skin temperature (Sk_8) from ≈28.0 to 35.0°C, where highest decreases occurred during SCE exposures. The core temperature had variations from ≈37.4 to 37.7°C.

In the figures 65, 66, 67 and 68 are illustrated industrial results on skin and core temperature data recorded for volunteer 2 on day 2 during morning and in figures 69, 70, 71 and 72 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

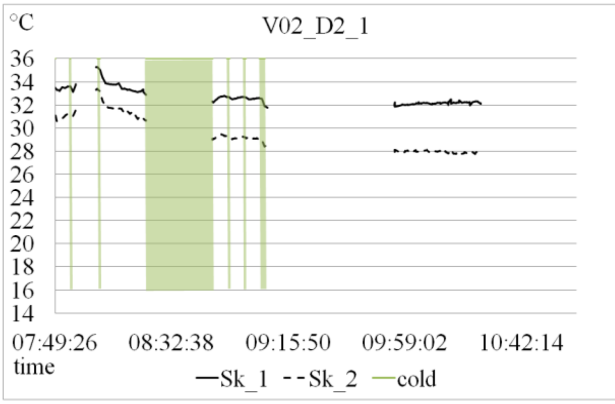


Figure 65 – Results for the volunteer 2 on day 2 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

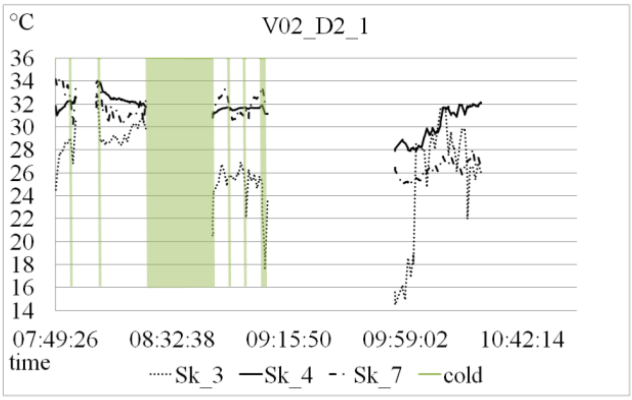


Figure 66 – Results for the volunteer 2 on day 2 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

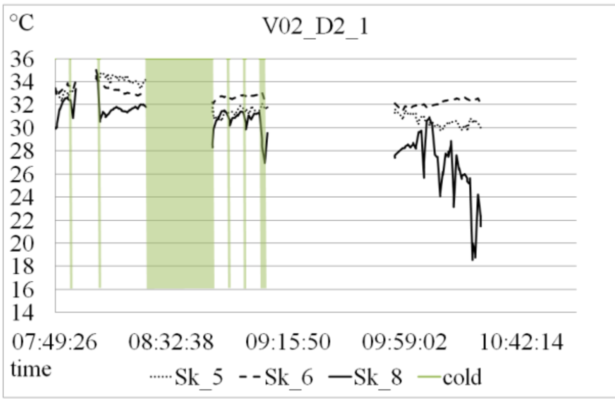


Figure 67 – Results for the volunteer 2 on day 2 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

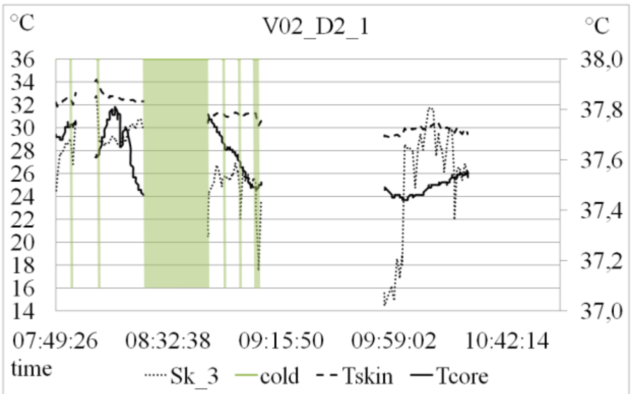


Figure 68 – Results for the volunteer 2 on day 2 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 35.0°C, with lower values after SCE exposures. Left hand skin temperature (Sk_3) variations were highest, varying from ≈14.0 to 32.0°C. The highest hand skin temperature decreases occurred after SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈25.0 to 34.0°C. The chest skin temperature (Sk_5) had variations from ≈30.0 to 35.0°C, right scapula (Sk_6) from ≈32.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈19.5 to 34.0°C, with decreases after SCE exposures. The core temperature had variations from ≈37.4 to 37.8°C.

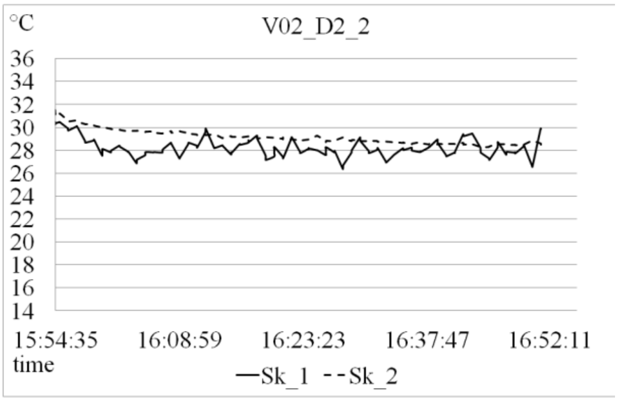


Figure 69 – Results for the volunteer 2 on day 2 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

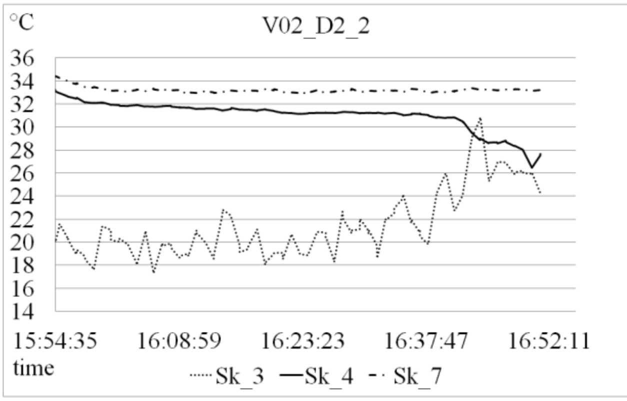


Figure 70 – Results for the volunteer 2 on day 2 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

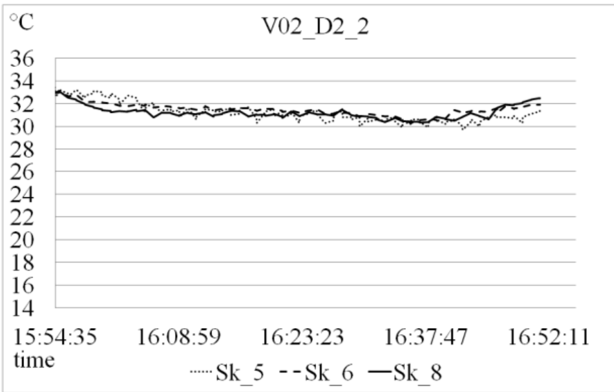


Figure 71 – Results for the volunteer 2 on day 2 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

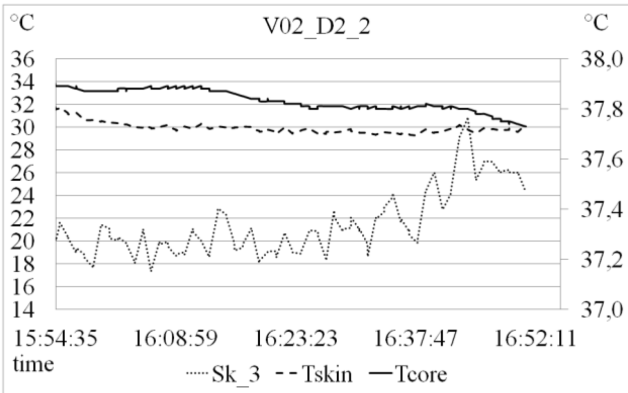


Figure 72 – Results for the volunteer 2 on day 2 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈27.5 to 32.0°C. Left hand skin temperature (Sk_3) variations were highest, varying from ≈18.0 to 30.5°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈26.5 to 34°C during all recorded period. The chest skin temperature (Sk_5), right scapula (Sk_6) and forehead skin temperature (Sk_8) had variations from ≈30.0 to 33.0°C. The core temperature had variations from ≈37.7 to 37.9°C.

In the figures 73, 74, 75 and 76 are illustrated industrial results on skin and core temperature data recorded for volunteer 2 on day 3 during morning and in figures 77, 78, 79 and 80 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

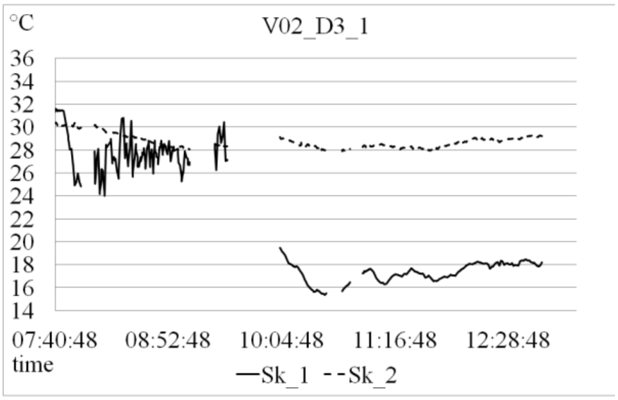


Figure 73 – Results for the volunteer 2 on day 3 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

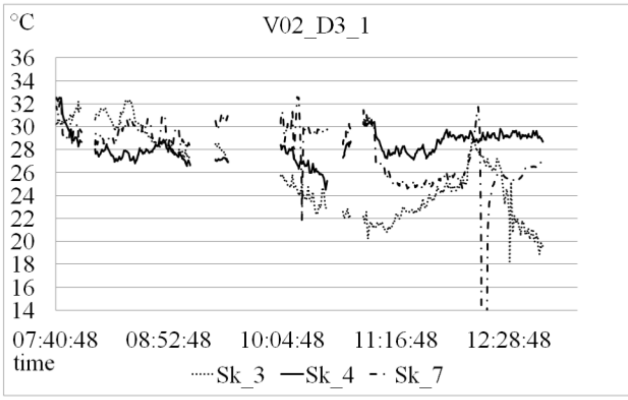


Figure 74 – Results for the volunteer 2 on day 3 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

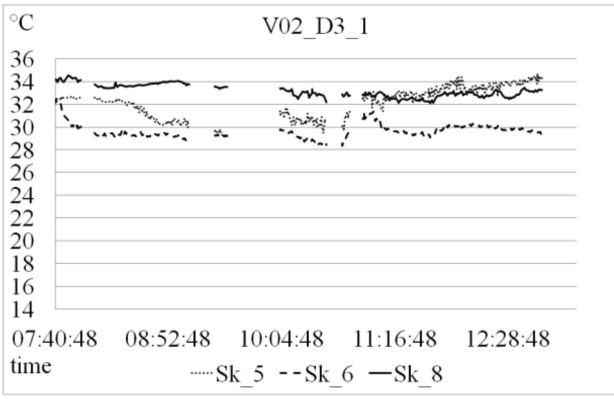


Figure 75 – Results for the volunteer 2 on day 3 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

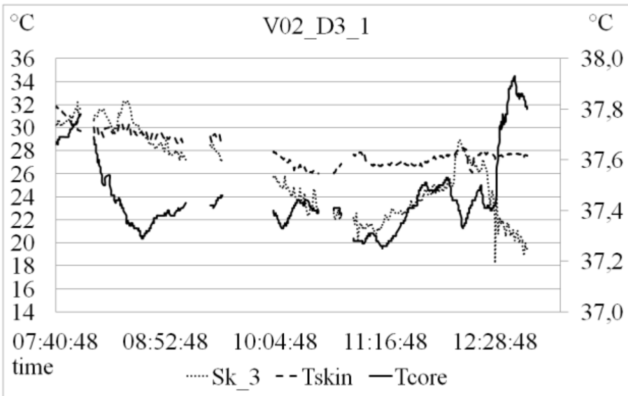


Figure 76 – Results for the volunteer 2 on day 3 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈16.5 to 32.0°C. Left hand skin temperature (Sk_3) variations were highest, varying from ≈19.0 to 32.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈25 to 32°C. The chest skin temperature (Sk_5) had variations from ≈30.0 to 33.0°C, right scapula (Sk_6) from ≈28.0 to 32.0°C and forehead skin temperature (Sk_8) from ≈32.0 to 35.0°C. The core temperature had variations from ≈37.3 to 38.0°C.

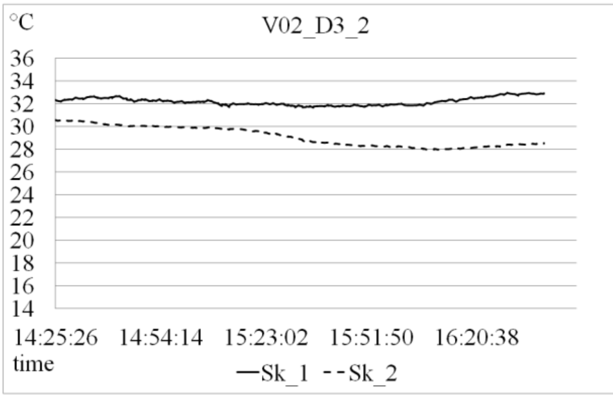


Figure 77 – Results for the volunteer 2 on day 3 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

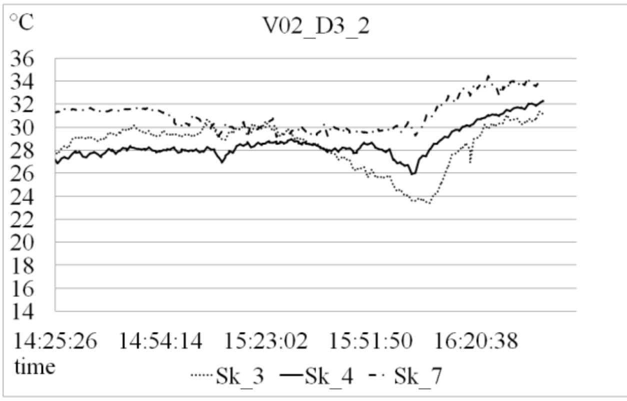


Figure 78 – Results for the volunteer 2 on day 3 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

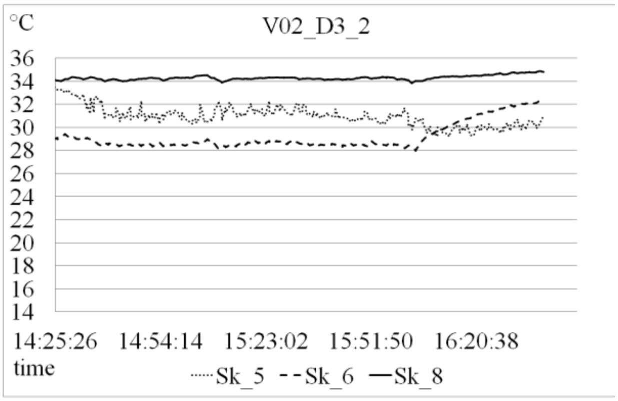


Figure 79 – Results for the volunteer 2 on day 3 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

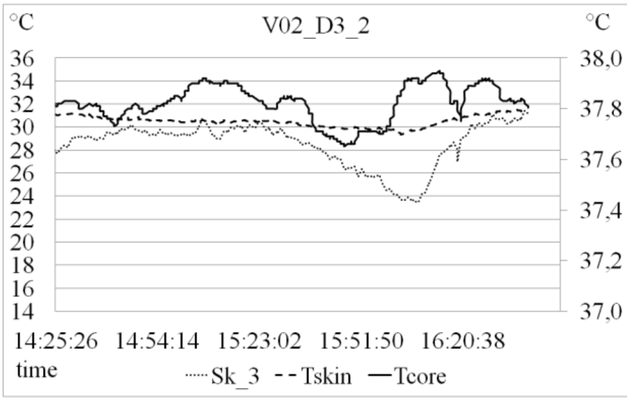


Figure 80 – Results for the volunteer 2 on day 3 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 33.0°C. Left hand skin temperature (Sk_3) variations were highest, varying from ≈23.5 to 31.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈26.0 to 34.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈30.0 to 34.0°C, right scapula (Sk_6) from ≈28.0 to 32.0°C and forehead skin temperature (Sk_8) from ≈34.0 to 35.0°C. The core temperature had variations from ≈37.7 to 38.0°C.

In the figures 81, 82, 83 and 84 are illustrated industrial results on skin and core temperature data recorded for volunteer 3 on day 1 during morning and in figures 85, 86, 87 and 88 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

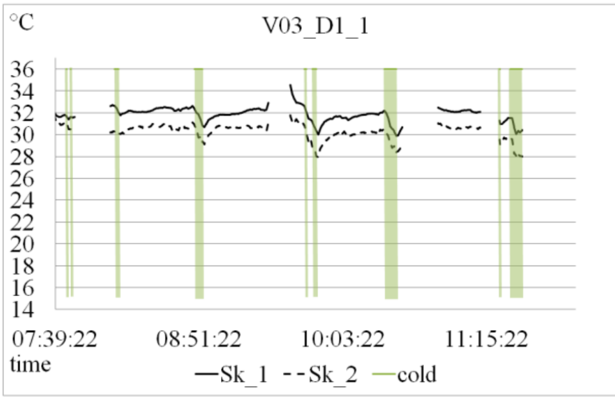


Figure 81 – Results for the volunteer 3 on day 1 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

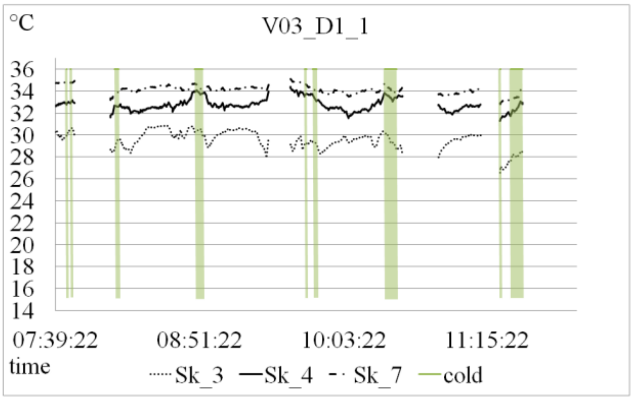


Figure 82 – Results for the volunteer 3 on day 1 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

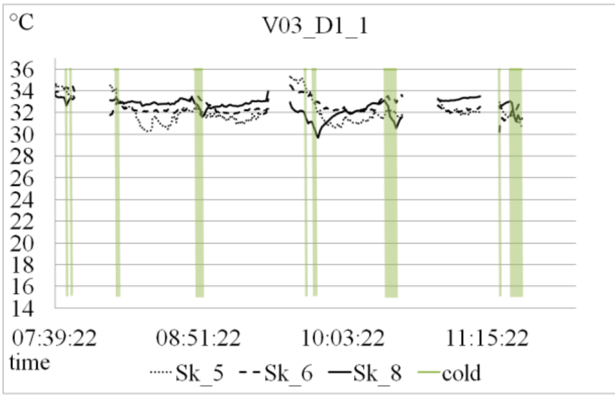


Figure 83 – Results for the volunteer 3 on day 1 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

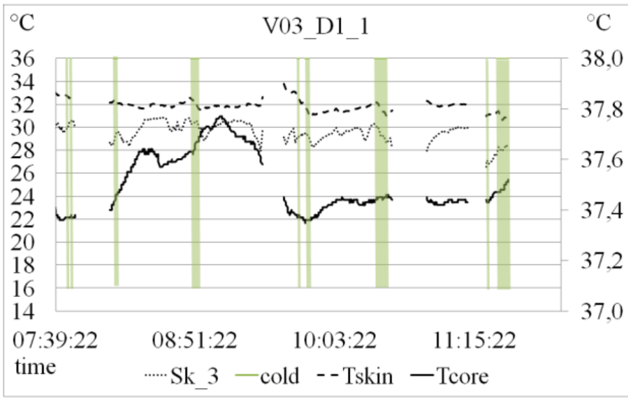


Figure 84 – Results for the volunteer 3 on day 1 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 24.0°C, with lowest recorded values after SCE exposure. Left hand skin temperature (Sk_3) had variations from ≈28.0 to 31.0°C. The highest hand skin temperature decreases occurred during SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈32.0 to 35.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈30.0 to 35.0°C, right scapula (Sk_6) from ≈32.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈30.0 to 34.0°C, with highest decreases after SCE exposures. The core temperature had variations from ≈37.4 to 37.8°C, with most increases occurring during SCE exposures.

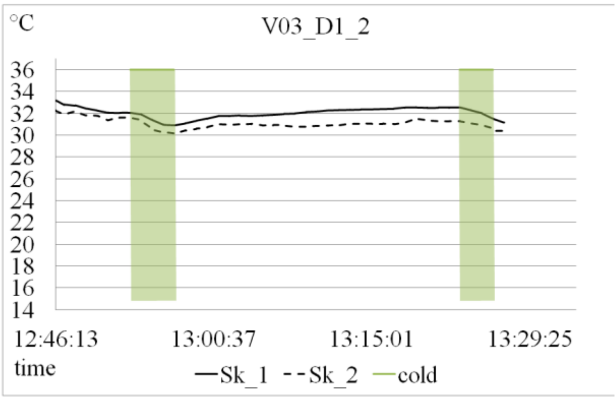


Figure 85 – Results for the volunteer 3 on day 1 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

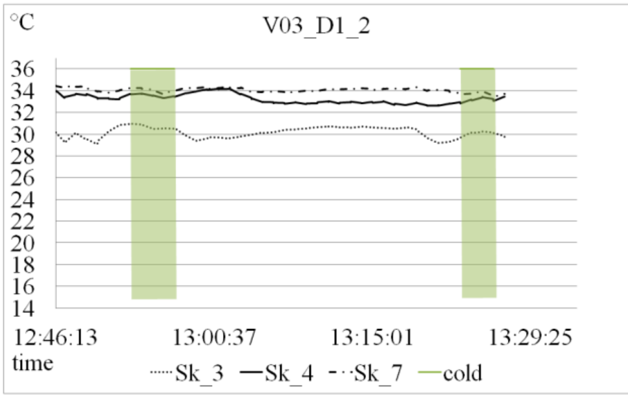


Figure 86 – Results for the volunteer 3 on day 1 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

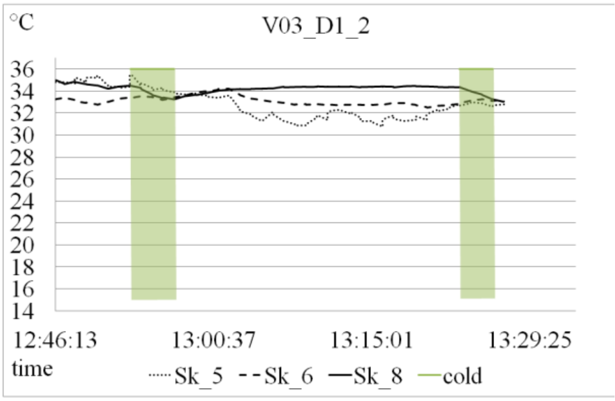


Figure 87 – Results for the volunteer 3 on day 1 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

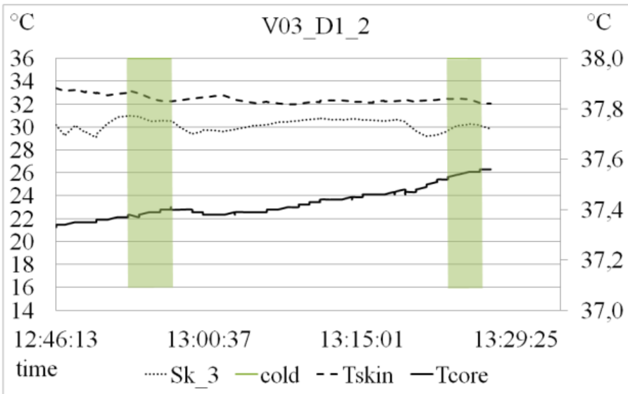


Figure 88 – Results for the volunteer 3 on day 1 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈30.0 to 33.0°C, with lowest recorded values after SCE exposures. Left hand skin temperature (Sk_3) had variations from ≈29.0 to 31.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈32.0 to 35.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈31.0 to 35.0°C, right scapula (Sk_6) from ≈32.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈33.0 to 35.0°C, where highest decreases occurred during SCE exposures. The core temperature had variations from ≈37.3 to 37.6°C, increasing constantly from the start till the end of the working period.

In the figures 89, 90, 91 and 92 are illustrated industrial results on skin and core temperature data recorded for volunteer 3 on day 2 during morning and in figures 93, 94, 95 and 96 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

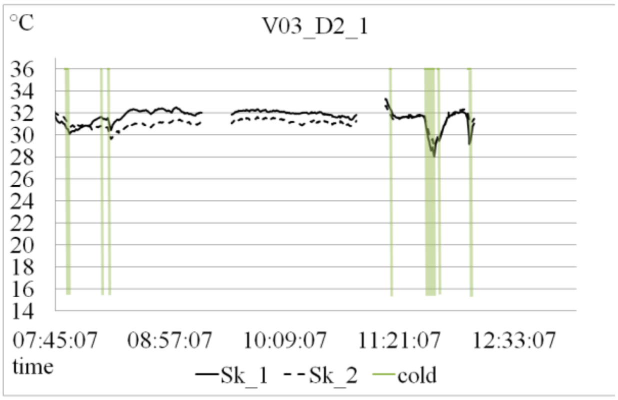


Figure 89 – Results for the volunteer 3 on day 2 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

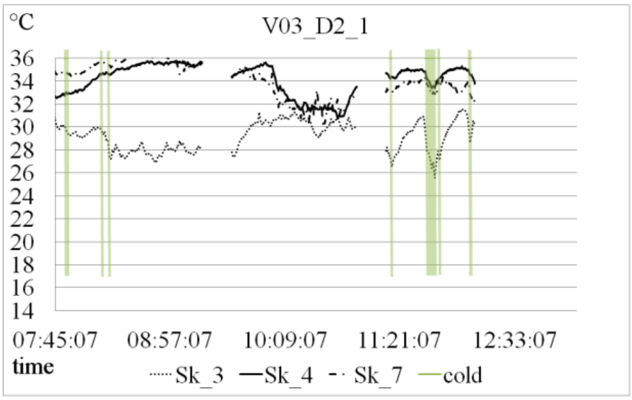


Figure 90 – Results for the volunteer 3 on day 2 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

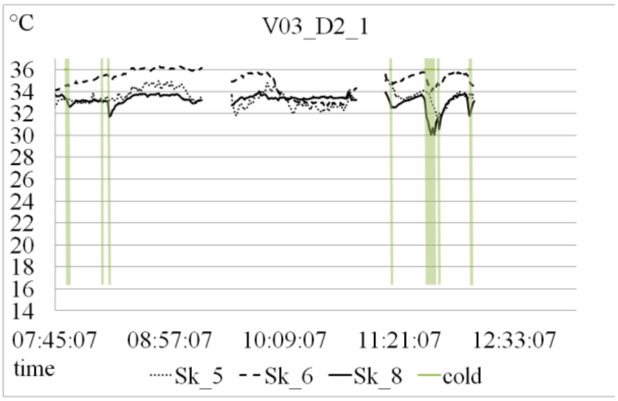


Figure 91 – Results for the volunteer 3 on day 2 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

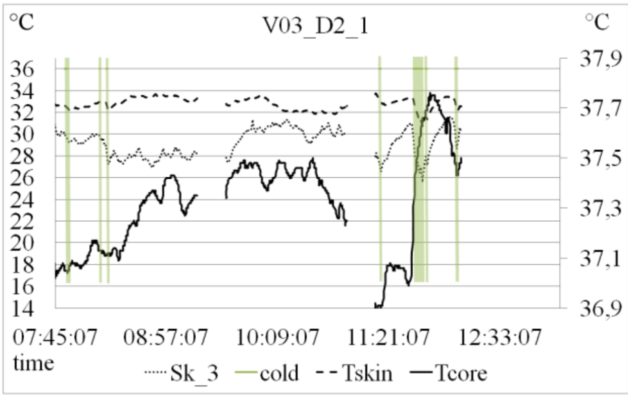


Figure 92 – Results for the volunteer 3 on day 2 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈28.0 to 33.0°C, with lowest recorded values after SCE exposures and highest decrease after the longest SCE exposure. Left hand skin temperature (Sk_3) had variations from ≈26.0 to 31.5°C. The highest hand skin temperature decreases occurred after SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈31.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈32.0 to 35.0°C, right scapula (Sk_6) from ≈33.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈30.0 to 34.0°C, with highest decreases after SCE exposures. The core temperature had variations from ≈36.9 to 37.8°C, with the highest increase occurring during the longest SCE exposure.

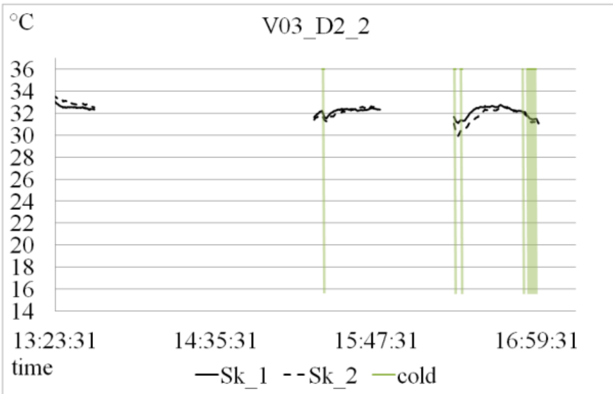


Figure 93 – Results for the volunteer 3 on day 2 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

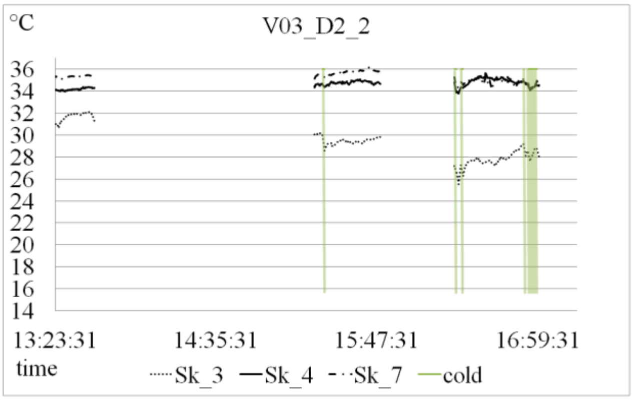


Figure 94 – Results for the volunteer 3 on day 2 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

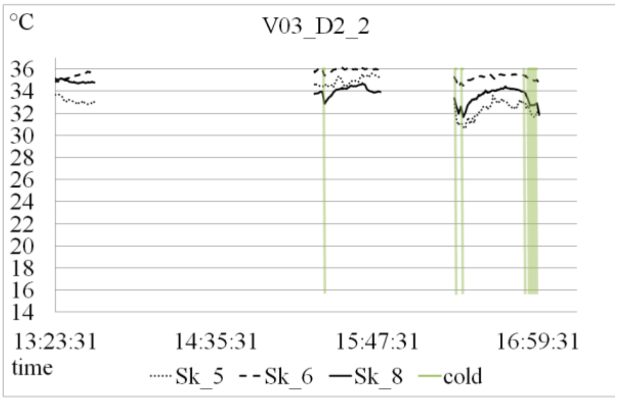


Figure 95 – Results for the volunteer 3 on day 2 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

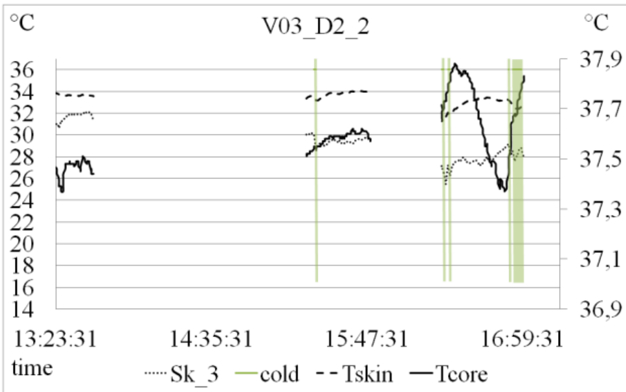


Figure 96 – Results for the volunteer 3 on day 2 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈30.0 to 33.5°C, with lowest recorded values after SCE exposures. Left hand skin temperature (Sk_3) had variations from ≈26.0 to 32.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈34.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈31.0 to 36.0°C, right scapula (Sk_6) from ≈34.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈32 to 35°C, where highest decreases occurred during SCE exposures. The core temperature had variations from ≈37.4 to 37.9°C, with highest increases after SCE exposures.

In the figures 97, 98, 99 and 100 are illustrated industrial results on skin and core temperature data recorded for volunteer 4 on day 1 during morning and in figures 101, 102, 103 and 104 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

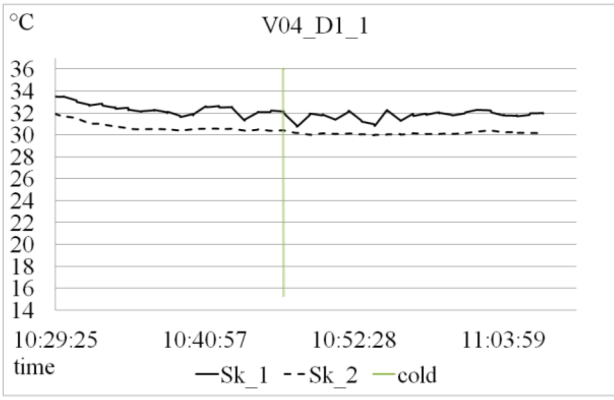


Figure 97 – Results for the volunteer 4 on day 1 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

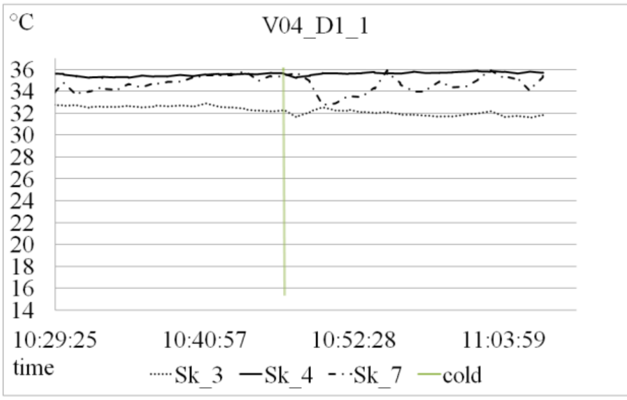


Figure 98 – Results for the volunteer 4 on day 1 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations,

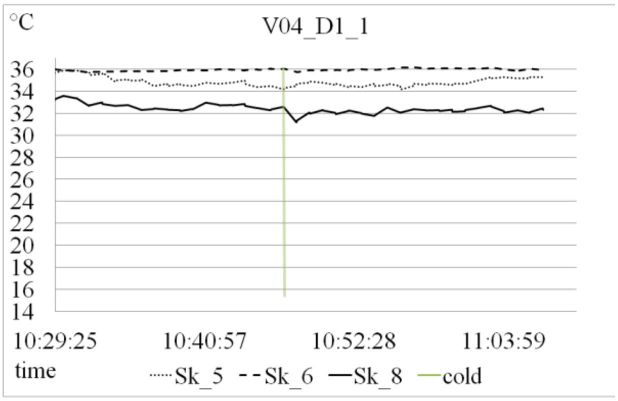


Figure 99 – Results for the volunteer 4 on day 1 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

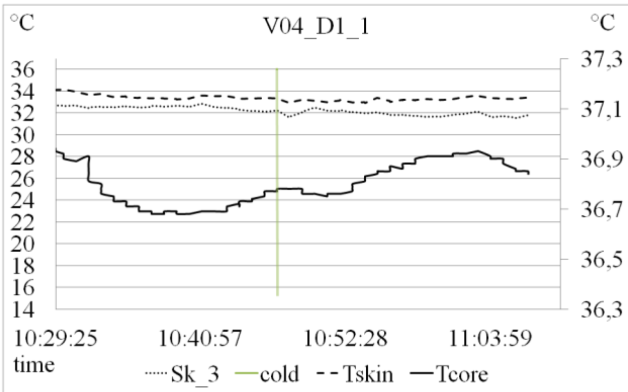


Figure 100 – Results for the volunteer 4 on day 1 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈30.0 to 34.0°C. Left hand skin temperature (Sk_3) had variations from ≈31.5 to 32.5°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈33.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈34.0 to 36.0°C, right scapula (Sk_6) from ≈36.0°C and forehead skin temperature (Sk_8) from ≈31.0 to 34.0°C. The core temperature had variations from ≈36.7 to 37.0°C.

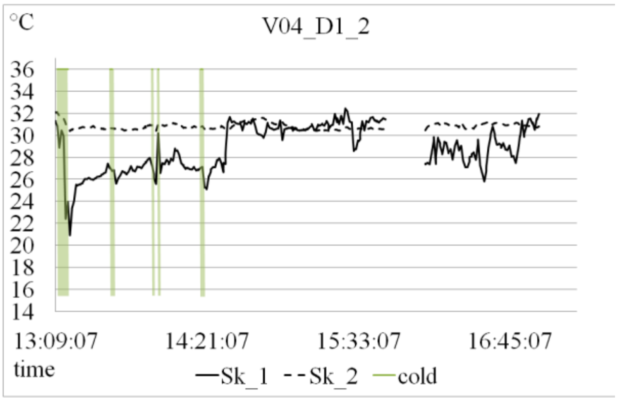


Figure 101 – Results for the volunteer 4 on day 1 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

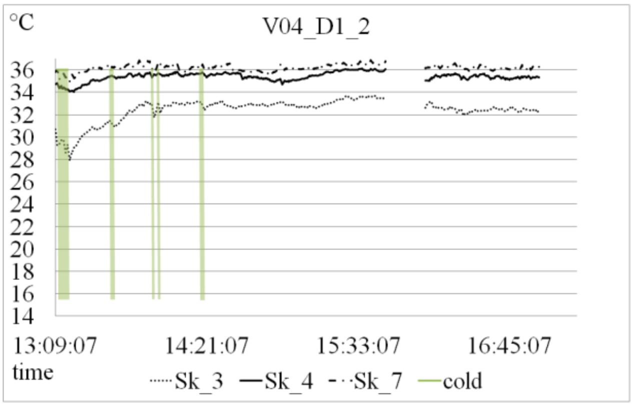


Figure 102 – Results for the volunteer 4 on day 1 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

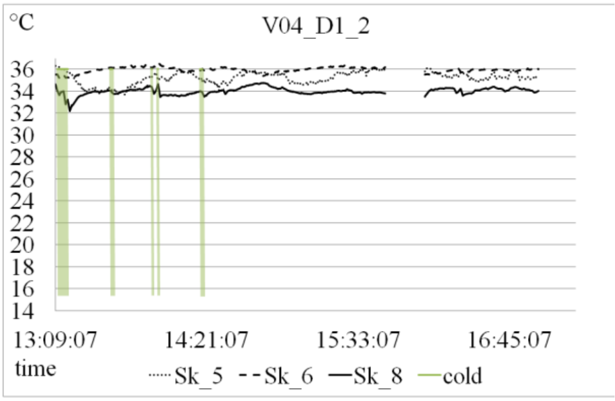


Figure 103 – Results for the volunteer 4 on day 1 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

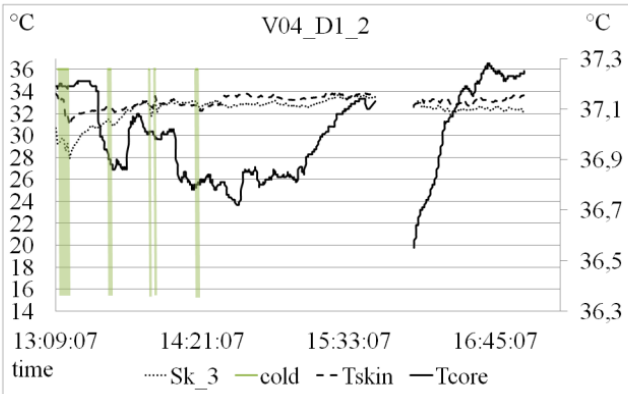


Figure 104 – Results for the volunteer 4 on day 1 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈21.0 to 32.0°C, with lowest recorded values after SCE exposures. Left hand skin temperature (Sk_3) had variations from ≈28.0 to 34.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈34.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈34.0 to 36.0°C, right scapula (Sk_6) from ≈35.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈32.0 to 35.0°C, where highest decreases occurred during SCE exposures. The core temperature had variations from ≈36.6 to 37.3°C, with highest increases after SCE exposures.

In the figures 105, 106, 107 and 108 are illustrated industrial results on skin and core temperature data recorded for volunteer 4 on day 2 during morning and in figures 109, 110, 111 and 112 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

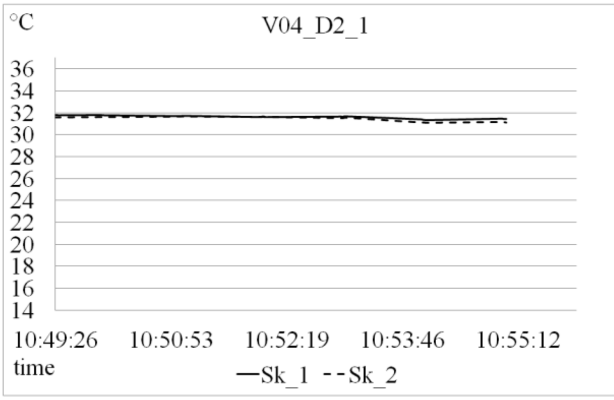


Figure 105 – Results for the volunteer 4 on day 2 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

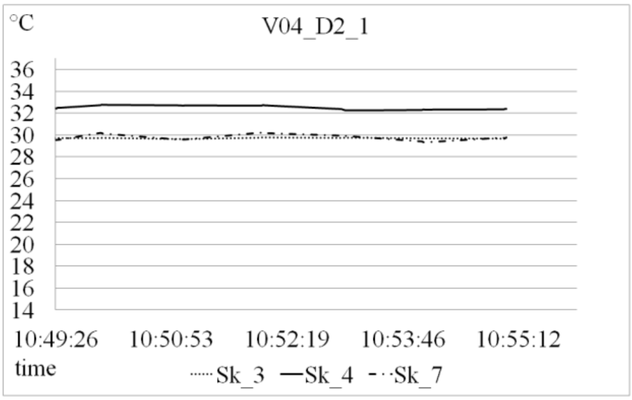


Figure 106 – Results for the volunteer 4 on day 2 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

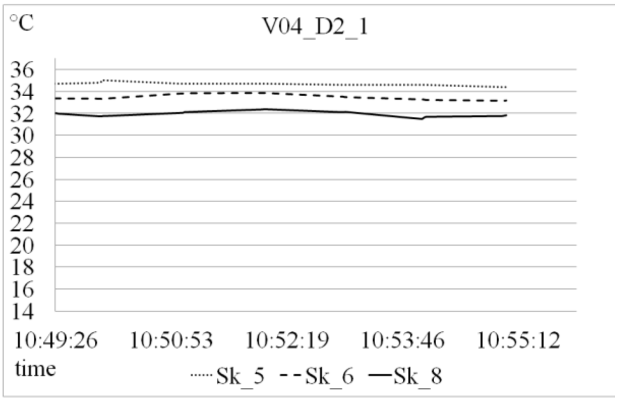


Figure 107 – Results for the volunteer 4 on day 2 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

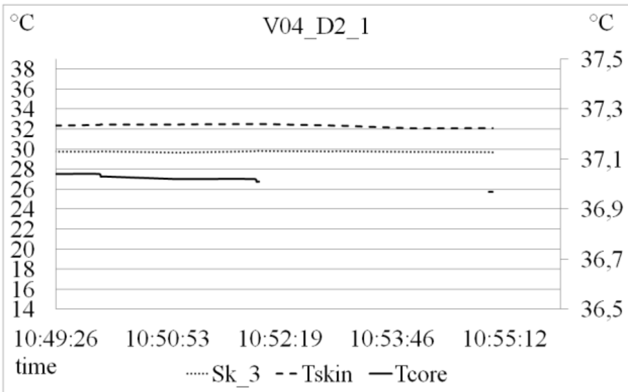


Figure 108 – Results for the volunteer 4 on day 2 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈31.0 to 32.0°C. Left hand skin temperature (Sk_3) was ≈30.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈30.0 to 33.0°C during all recorded period. The chest skin temperature (Sk_5) was ≈35.0°C, right scapula (Sk_6) from ≈33.0 to 34.0°C and forehead skin temperature (Sk_8) from ≈31.0 to 32.0°C. The core temperature was ≈37.1°C.

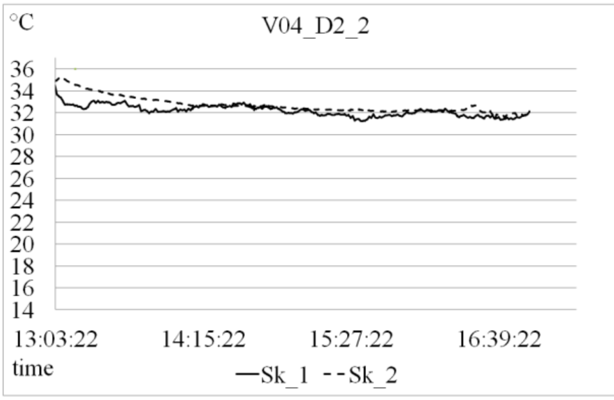


Figure 109 – Results for the volunteer 4 on day 2 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

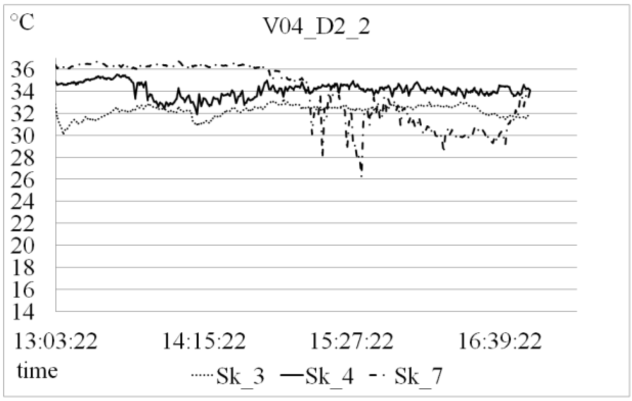


Figure 110 – Results for the volunteer 4 on day 2 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

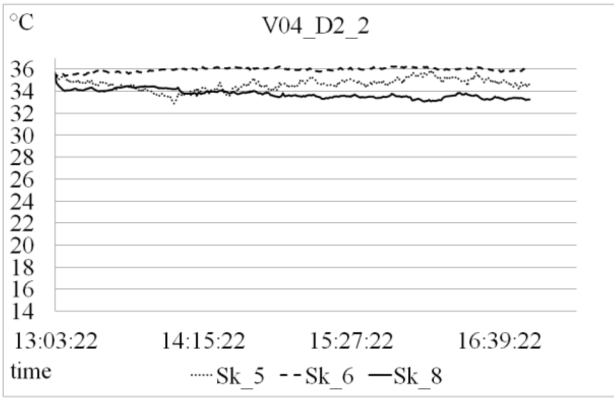


Figure 111 – Results for the volunteer 4 on day 2 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

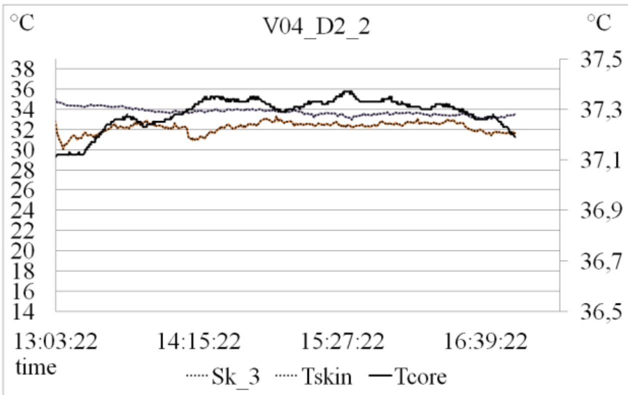


Figure 112 – Results for the volunteer 4 on day 2 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈31.0 to 35.0°C. Left hand skin temperature (Sk_3) had variations from ≈30.0 to 33.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈26.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈33.0 to 36.0°C, right scapula (Sk_6) from ≈35.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈33.0 to 35.0°C. The core temperature had variations from ≈37.2 to 37.4°C.

In the following figures 113, 114, 115 and 116 are illustrated industrial results on skin and core temperature data recorded for volunteer 4 on day 3 during morning and in figures 117, 118, 119 and 120 during afternoon work. Periods within the severe cold chamber are marked by vertical shaded areas. On the left side axis are illustrated values for the skin temperature values, while on the right side axis are illustrated the core temperature values.

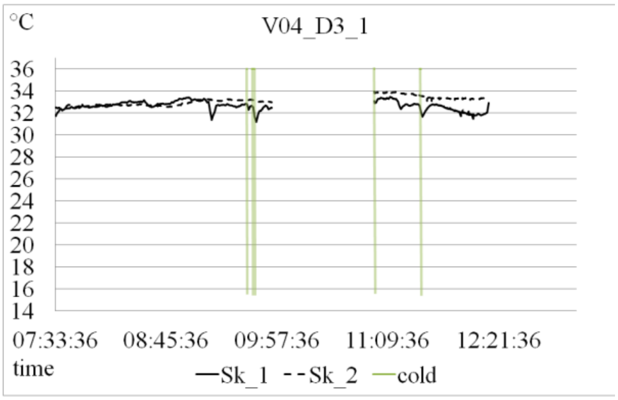


Figure 113 – Results for the volunteer 4 on day 3 morning, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

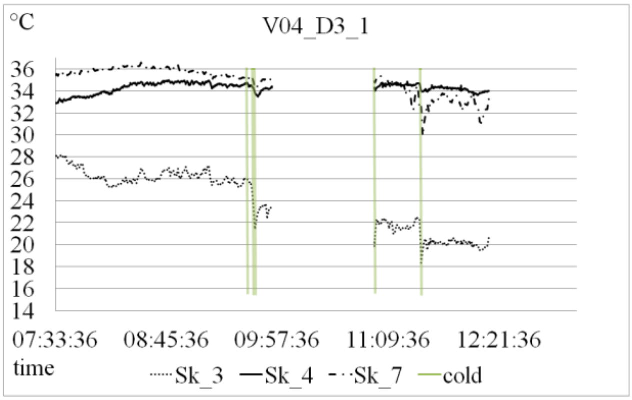


Figure 114 – Results for the volunteer 4 on day 3 morning, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

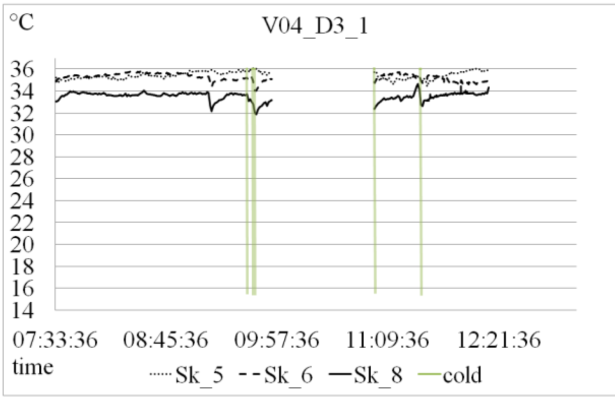


Figure 115 – Results for the volunteer 4 on day 3 morning, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

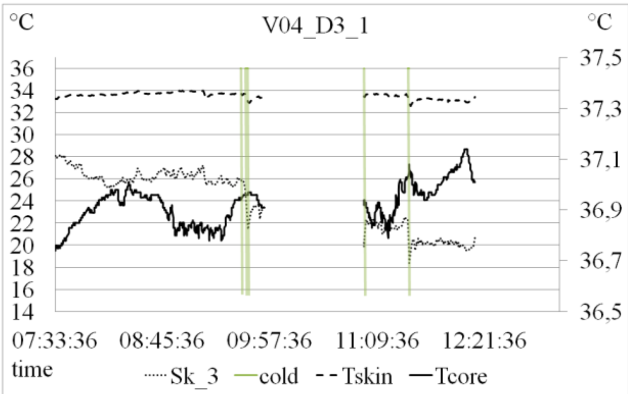


Figure 116 – Results for the volunteer 4 on day 3 morning, left hand (Sk_3), Tskin and Tcore temperature variations.

During the morning period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈31.0 to 34.0°C, with lowest recorded values after SCE exposures. Left hand skin temperature (Sk_3) had variations from ≈18.0 to 28.0°C. The highest hand skin temperature decreases occurred after SCE exposures. Both the decrease and recovery of the hand skin temperature was fast. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈30.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈35.0 to 36.0°C, right scapula (Sk_6) from ≈34.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈32.0 to 35.0°C, with highest decreases after SCE exposures. The core temperature had variations from ≈36.7 to 37.1°C.

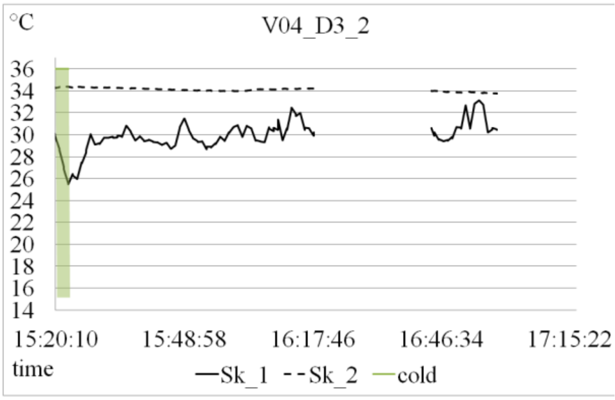


Figure 117 – Results for the volunteer 4 on day 3 afternoon, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

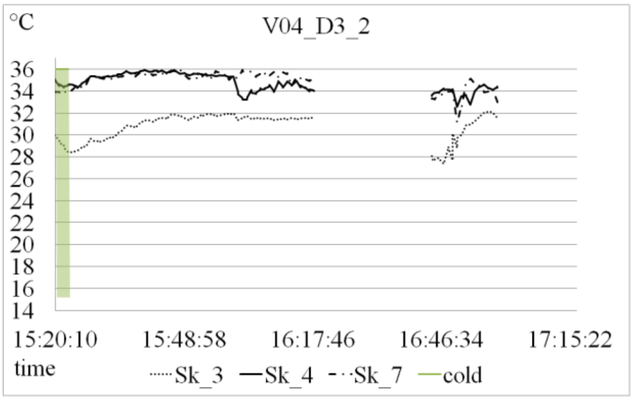


Figure 118 – Results for the volunteer 4 on day 3 afternoon, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

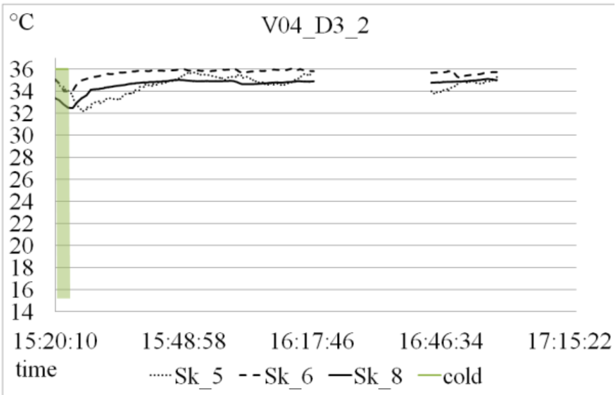


Figure 119 – Results for the volunteer 4 on day 3 afternoon, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

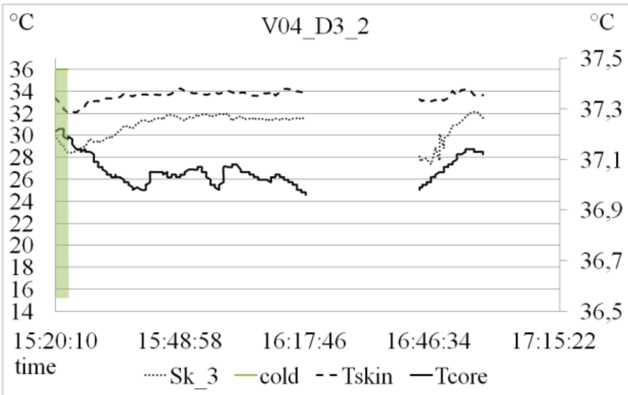


Figure 120 – Results for the volunteer 4 on day 3 afternoon, left hand (Sk_3), Tskin and Tcore temperature variations.

During the afternoon period, legs skin temperatures (Sk_1 and Sk_2) had variations from ≈26.0 to 34.0°C, with lowest left calf (Sk_1) recorded value after the SCE exposure. Left hand skin temperature (Sk_3) had variations from ≈28.0 to 32.0°C. The arms skin temperatures (Sk_4 and Sk_7) had variations from ≈31.0 to 36.0°C during all recorded period. The chest skin temperature (Sk_5) had variations from ≈32.0 to 36.0°C, right scapula (Sk_6) from ≈34.0 to 36.0°C and forehead skin temperature (Sk_8) from ≈32.0 to 35.0°C, where highest decreases occurred during the SCE exposure. The core temperature had variations from ≈37.0 to 37.2°C.

5.2.4 Fully monitored workers Acc and Tcore variations

In the figures 121, 122, 123, 124, 125 and 126 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 1 on day 1 morning. Periods within the severe cold chamber are marked by vertical green shaded areas, while periods within the severe hot thermal environment (outside) are marked with vertical purple shaded areas. On the left side axis in the first core temperature variations graph are illustrated values for the core temperature. On other graphs, on the left side axis are illustrated accelerometry values, while on the right side axis are illustrated the core temperature values.

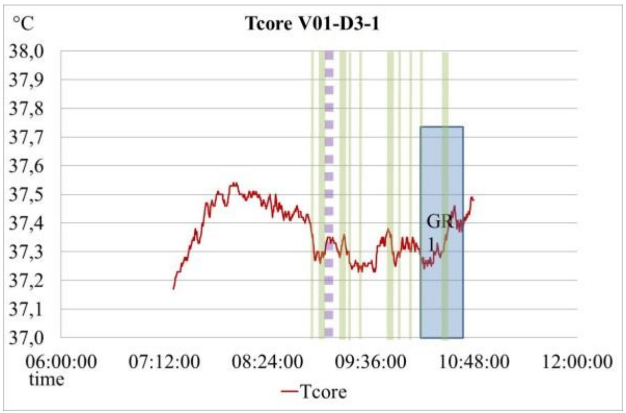


Figure 121 – Results for the volunteer 1 on day 1 morning, core temperature variations (the shaded blue area represent selected GR1 period).

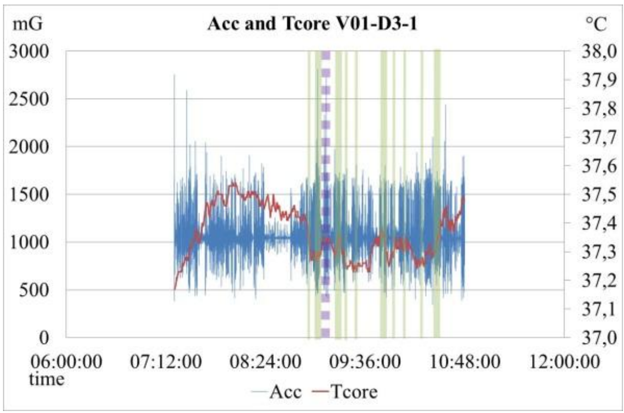


Figure 122 – Results for the volunteer 1 on day 1 morning, total accelerometry (Acc) and core temperature variations.

In the figure 122 accelerometry data show a high movement till 08:24 which was followed by an increase in core temperature. Afterward, while there was little movement, Tcore start slowly decreasing (with a delay). With a new increase in movement, Tcore stopped decreasing with a delay.

The shaded blue part on the figure 121 represent the part GR1 which was observer separately as occurred a high increase in core temperature.

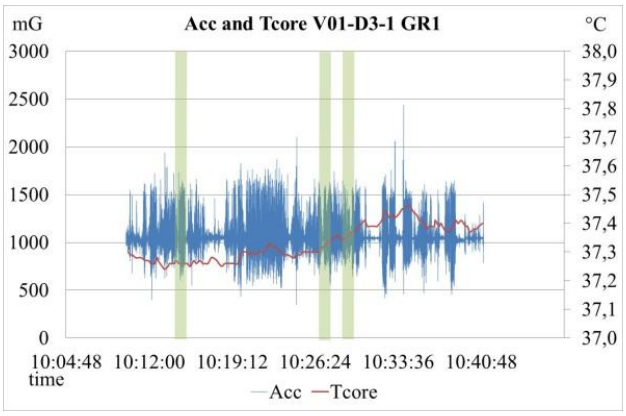


Figure 123 – Results for the volunteer 1 on day 1 morning, selected GR1 time period from 10:10 to 10:40 hours, total accelerometry (Acc) and core temperature variations.

In the figure 123 it is visible that core temperature follows increase and decrease of the movement (recorded accelerometry).

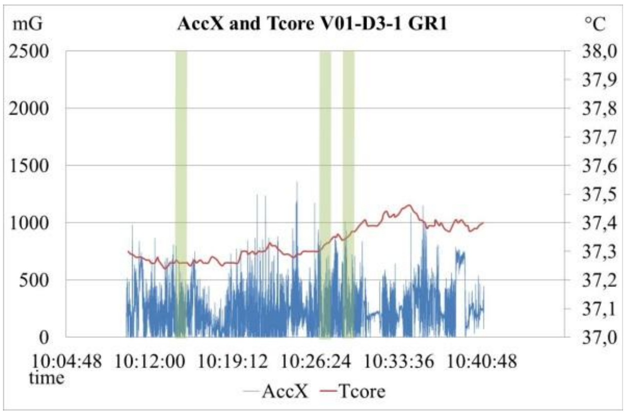


Figure 124 – Results for the volunteer 1 on day 1 morning, selected GR1 time period from 10:10 to 10:40 hours, lateral accelerometry (AccX) and core temperature variations.

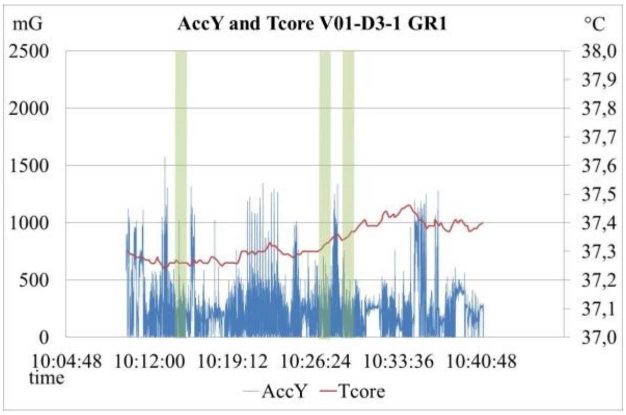


Figure 125 – Results for the volunteer 1 on day 1 morning, selected GR1 time period from 10:10 to 10:40 hours, longitudinal accelerometry (AccY) and core temperature variations.

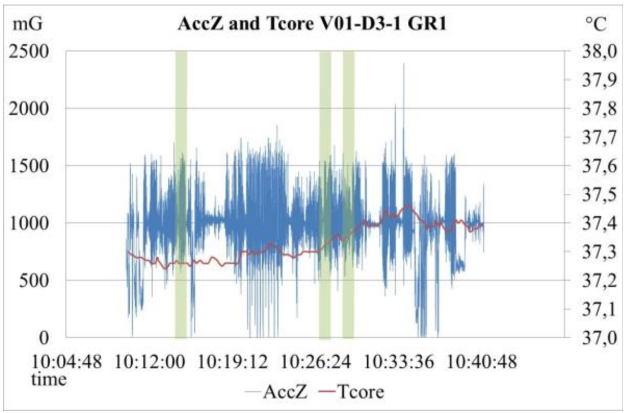


Figure 126– Results for the volunteer 1 on day 1 morning, selected GR1 time period from 10:10 to 10:40 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figure 127 are illustrated industrial results on accelerometry and core temperature data recorded for the volunteer 1 on day 1 afternoon.

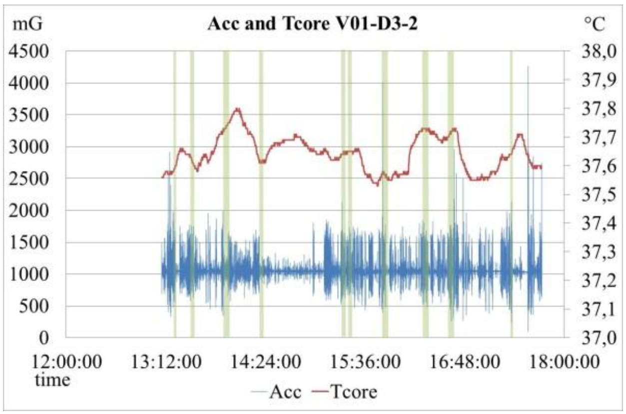


Figure 127 – Results for the volunteer 1 on day 1 afternoon, total accelerometry (Acc) and core temperature variations.

The shaded blue parts (GR1) were not selected for observing separately as no high increase or decrease in core temperature occurred during that afternoon.

In the figures 128-137 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 2 on day 3 morning. During that morning, the volunteer 2 was not exposed to SCE. On the left side axis in the first core temperature variations graph are illustrated values for the core temperature. On other graphs, on the left side axis are illustrated accelerometry values, while on the right side axis are illustrated the core temperature values.

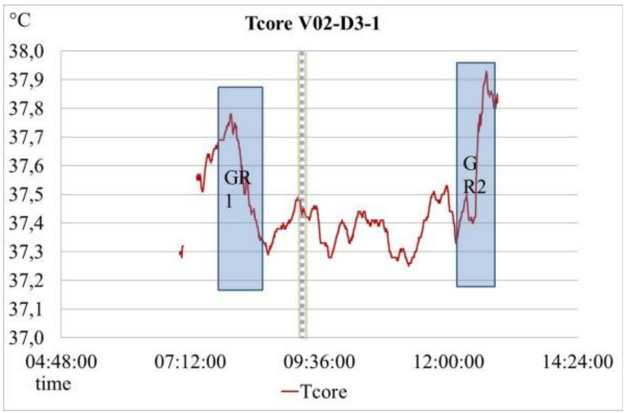


Figure 128 – Results for the volunteer 2 on day 3 morning, core temperature variations (the shaded blue areas represent selected GR1 and GR2 periods).

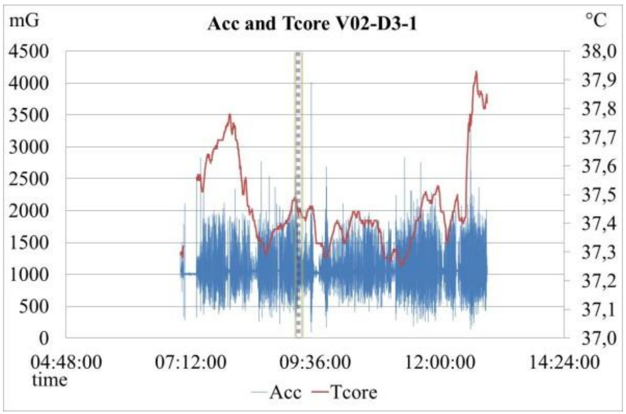


Figure 129 – Results for the volunteer 2 on day 3 morning, total accelerometry (Acc) and core temperature variations.

In the figure 129 at ≈07:55, accelerometry data show a decrease in movement. Tcore follows this decrease but with a few minutes delay. Tcore seemed always to follow the movement, increasing when the movement increased, and decreasing with a decrease in movement.

The shaded blue part on the figure 128 represent the part GR1 and GR2 were separately observed as highest decrease (in GR1) and higher increase (in GR2) of core temperature occurred.

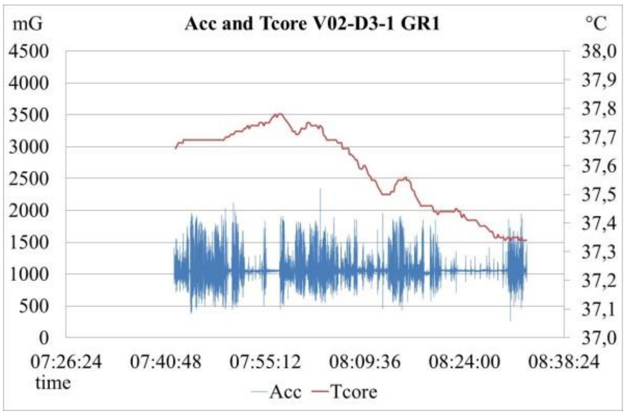


Figure 130 – Results for the volunteer 2 on day 3 morning, selected GR1 time period from 07:42 to 08:42 hours, total accelerometry (Acc) and core temperature variations.

In the figure 130, accelerometry data show low movement which is followed by a decrease in core temperature.

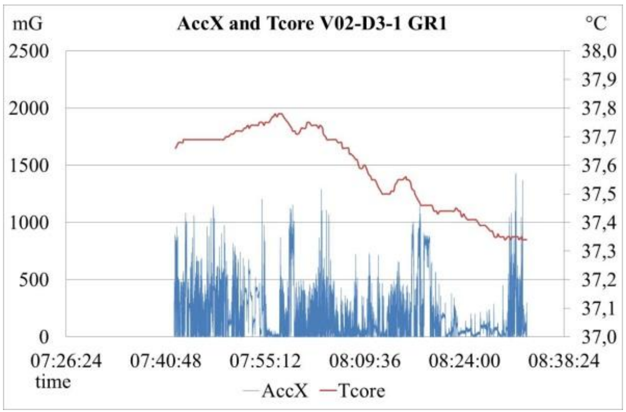


Figure 131 – Results for the volunteer 2 on day 3 morning, selected GR1 time period from 07:42 to 08:42 hours, lateral accelerometry (AccX) and core temperature variations.

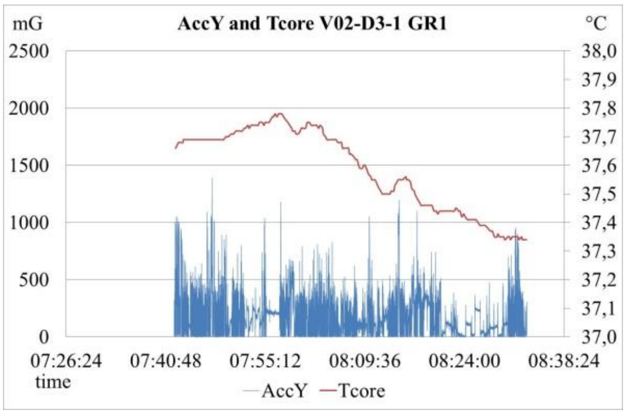


Figure 132 – Results for the volunteer 2 on day 3 morning, selected GR1 time period from 07:42 to 08:42 hours, longitudinal accelerometry (AccY) and core temperature variations.

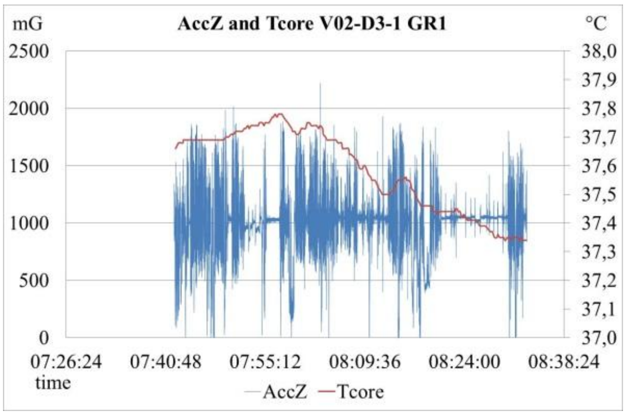


Figure 133 – Results for the volunteer 2 on day 3 morning, selected GR1 time period from 07:42 to 08:42 hours, vertical accelerometry (AccZ) and core temperature variations.

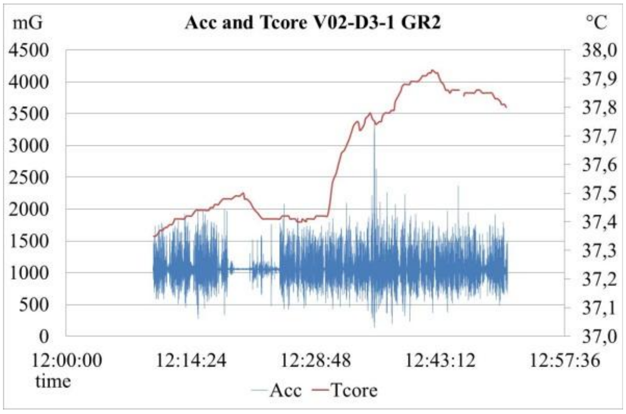


Figure 134 – Results for the volunteer 2 on day 3 morning, selected GR2 time period from 12:10 to 12:50 hours, total accelerometry (Acc) and core temperature variations.

In the figure 134, it is visible that the core temperature decreases with a delay when the movement decreases, and afterward starts rapidly increasing as the movement increased (from ≈37.4 to 37.9°C).

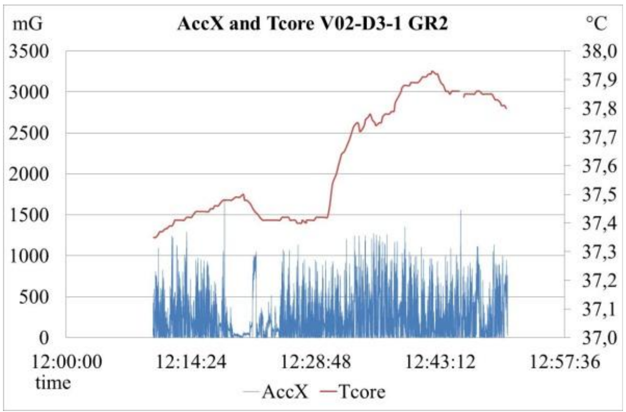


Figure 135 – Results for the volunteer 2 on day 3 morning, selected GR2 time period from 12:10 to 12:50 hours, lateral accelerometry (AccX) and core temperature variations.

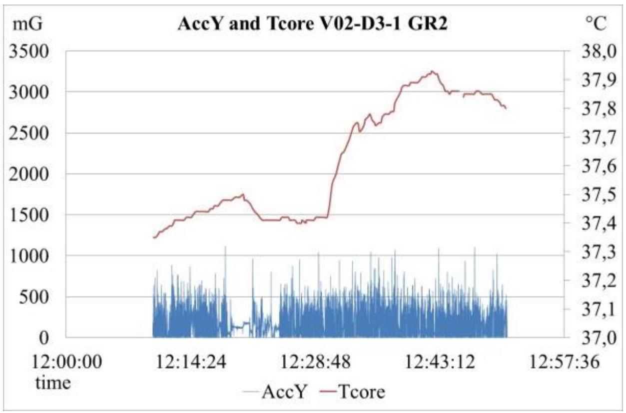


Figure 136 – Results for the volunteer 2 on day 3 morning, selected GR2 time period from 12:10 to 12:50 hours, longitudinal accelerometry (AccY) and core temperature variations.

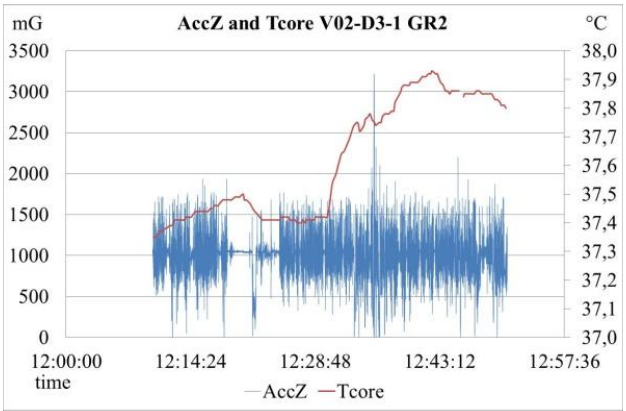


Figure 137 – Results for the volunteer 2 on day 3 morning, selected GR2 time period from 12:10 to 12:50 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figure 143 is visible that Tcore variations are following accelerometry peaks.

In the figures 138-143 are illustrated industrial results on accelerometry and core temperature data recorded for the volunteer 2 on day 3 afternoon. During that afternoon, the volunteer 2 was not exposed to SCE.

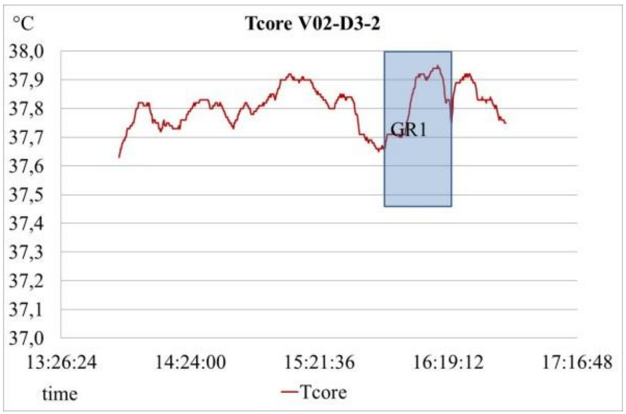


Figure 138 – Results for the volunteer 2 on day 3 afternoon, core temperature variations (the shaded blue area represent selected GR1 period).

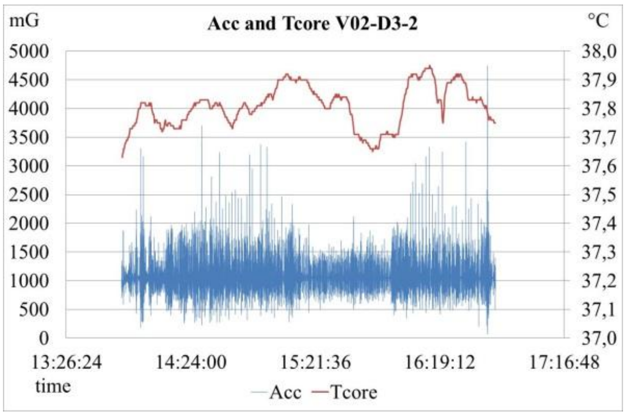


Figure 139 – Results for the volunteer 2 on day 3 afternoon, total accelerometry (Acc) and core temperature variations.

In the figure 139 is visible that the core temperature was increasing with increasing in movement (accelerometry data) and decreased when the movement decreased.

The shaded blue part on the figure 138 represent the part GR1 which was separately observed as occurred highest increase in core temperature.

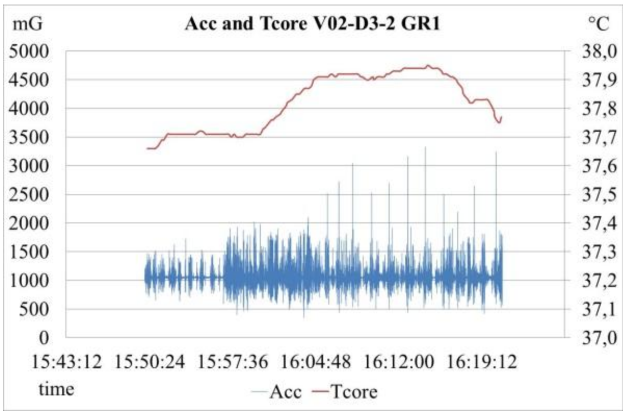


Figure 140 – Results for the volunteer 2 on day 3 afternoon, selected GR1 time period from 15:50 to 16:20 hours, total accelerometry (Acc) and core temperature variations.

In the figure 140, it is visible that the core temperature increases with a delay when the movement increases (from ≈37.7 to 37.95°C) and decreases afterward as the movement was reduced.

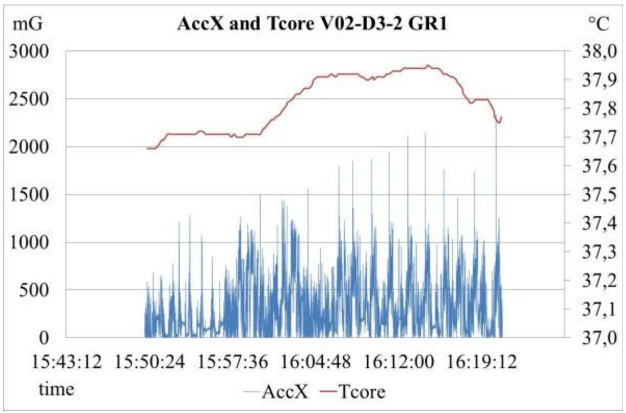


Figure 141 – Results for the volunteer 2 on day 3 afternoon, selected GR1 time period from 15:50 to 16:20 hours, lateral accelerometry (AccX) and core temperature variations.

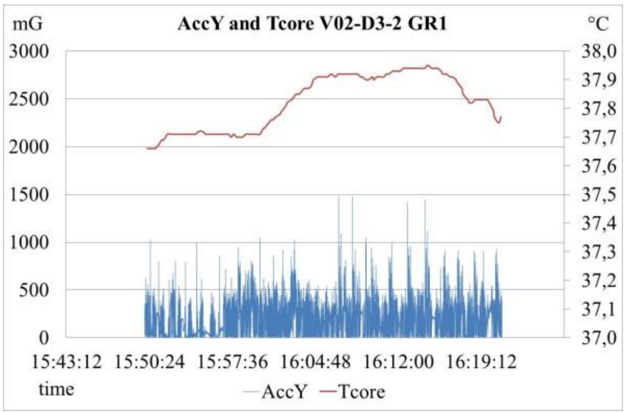


Figure 142 – Results for the volunteer 2 on day 3 afternoon, selected GR1 time period from 15:50 to 16:20 hours, longitudinal accelerometry (AccY) and core temperature variations.

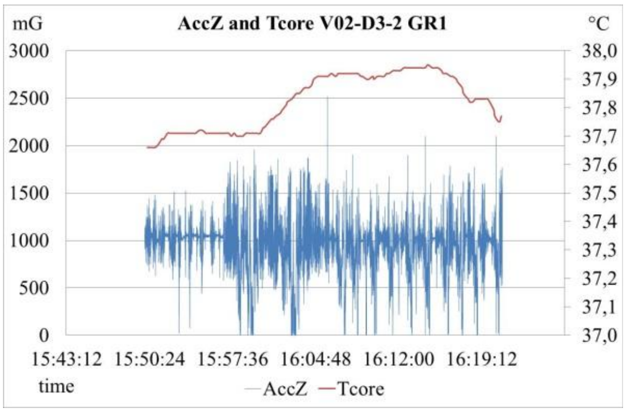


Figure 143 – Results for the volunteer 2 on day 3 afternoon, selected GR1 time period from 15:50 to 16:20 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figures 144-149 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 3 on day 2 morning. Periods within the severe cold chamber are marked by vertical green shaded areas, while periods within the severe hot thermal environment (outside) are marked with vertical purple shaded areas. On the left side axis in the first core temperature variations graph are illustrated values for the core temperature. On other graphs, on the left side axis are illustrated accelerometry values, while on the right side axis are illustrated the core temperature values.

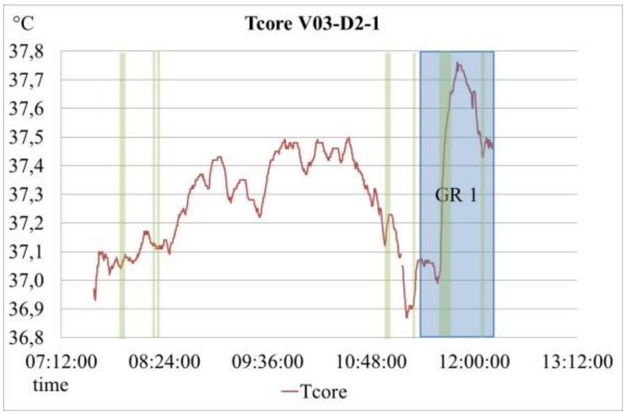


Figure 144 – Results for the volunteer 3 on day 2 morning, core temperature variations (the shaded blue area represent selected GR1 period).

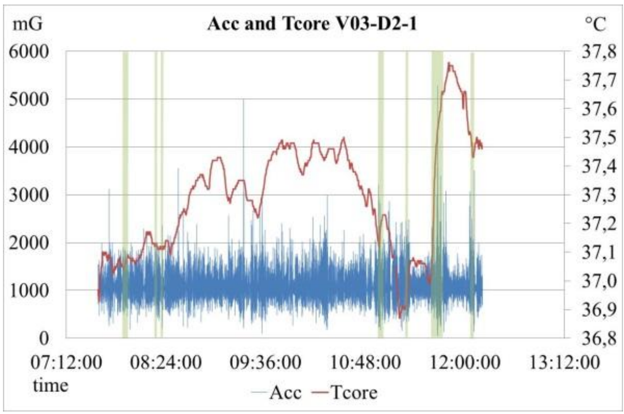


Figure 145 – Results for the volunteer 3 on day 2 morning, total accelerometry (Acc) and core temperature variations.

In the figure 145 is visible that the core temperature was increasing with increasing when the movement increased (accelerometry data) and decreased when the movement decreased. During the highest increase in core temperature, which occurred during the longest SCE exposure, accelerometry data show highest movement.

The shaded blue part on the figure 144 represent the part GR1 which was separately observed as occurred highest increase in core temperature.

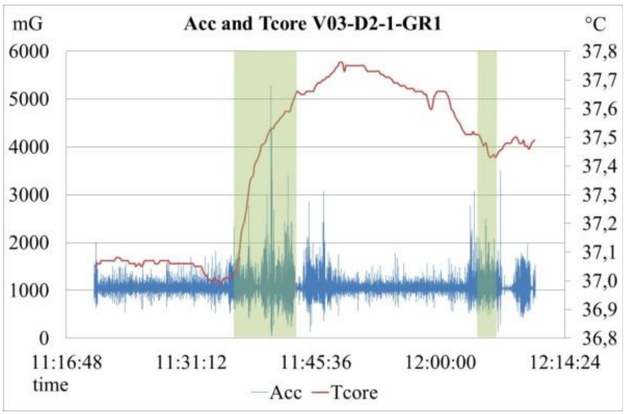


Figure 146 – Results for the volunteer 3 on day 2 morning, selected GR1 time period from 11:20 to 12:10 hours, total accelerometry (Acc) and core temperature variations.

In the figure 146, it is visible that the core temperature increases rapidly with exposure to SCE (from ≈37.0 to 37.7°C) and continued increasing even after exposure to SCE to ≈37.8°C. During the SCE exposure is also recorded high movement, which seem to be the reason for increasing the core temperature. As the movement was reduced, the core temperature starts decreasing.

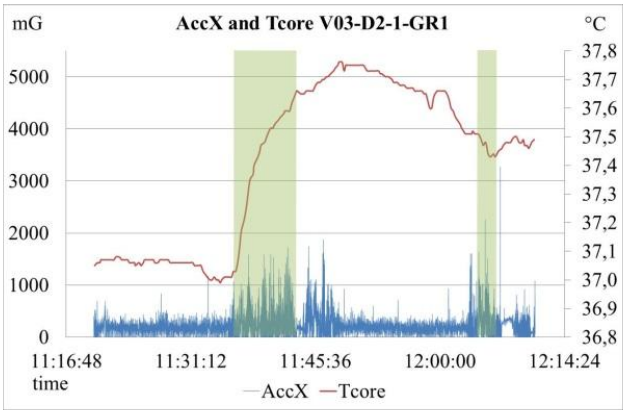


Figure 147 – Results for the volunteer 3 on day 2 morning, selected GR1 time period from 11:20 to 12:10 hours, lateral accelerometry (AccX) and core temperature variations.

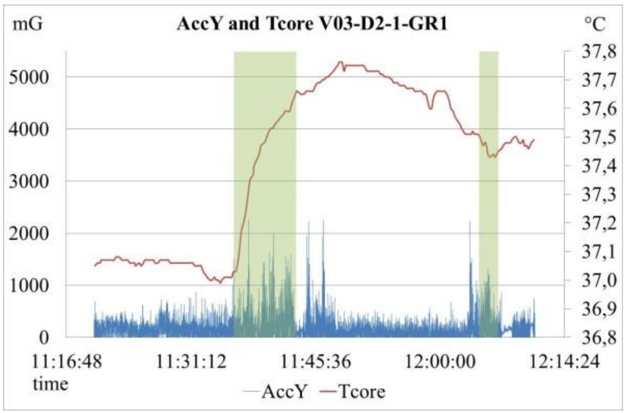


Figure 148 – Results for the volunteer 3 on day 2 morning, selected GR1 time period from 11:20 to 12:10 hours, longitudinal accelerometry (AccY) and core temperature variations.

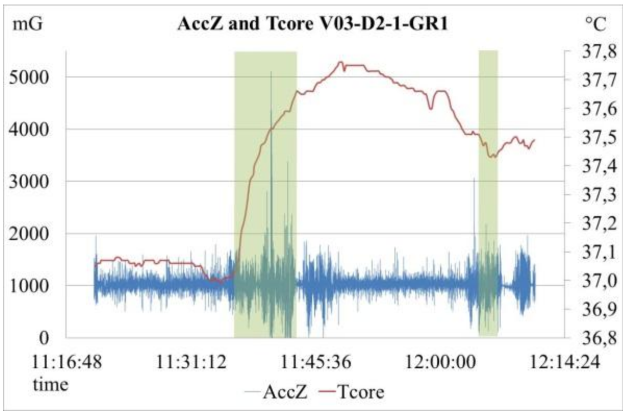


Figure 149 – Results for the volunteer 3 on day 2 morning, selected GR1 time period from 11:20 to 12:10 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figures 150-155 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 3 on day 2 afternoon.

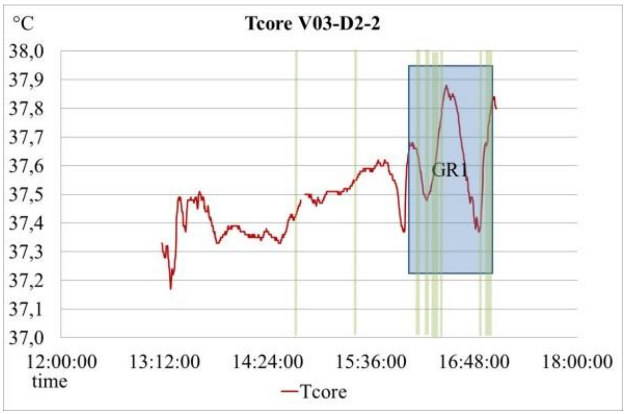


Figure 150 – Results for the volunteer 3 on day 2 afternoon, core temperature variations (the shaded blue area represent selected GR1 period).

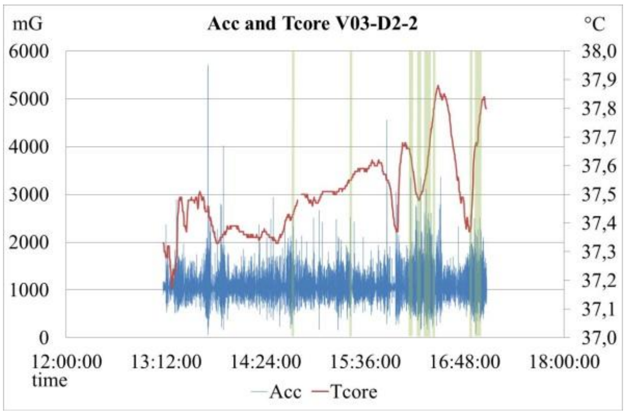


Figure 151 – Results for the volunteer 3 on day 2 afternoon, total accelerometry (Acc) and core temperature variations.

In the figure 151 is visible that the core temperature was increasing with increasing when the movement increased (accelerometry data) and decreased when the movement decreased. During SCE exposure was recorded highest increase in core temperature and in movement.

The shaded blue part on the figure 150 represent the part GR1 which was separately observed as occurred highest decrease and increase in core temperature and as the worker was repeatedly exposed to SCE.

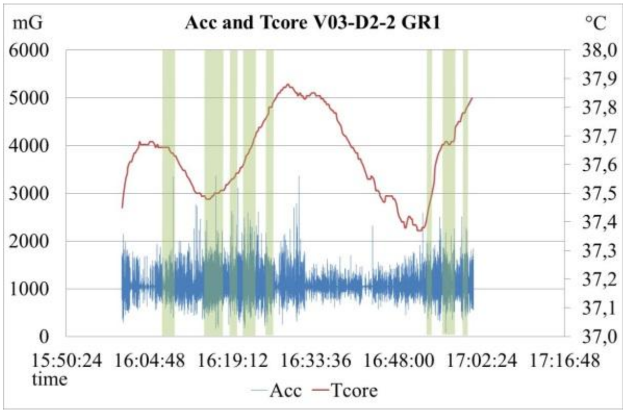


Figure 152 – Results for the volunteer 3 on day 2 afternoon, selected GR1 time period from 16:00 to 17:00 hours, total accelerometry (Acc) and core temperature variations.

In the figure 152, it is visible that the core temperature increases rapidly with exposure to SCE and with high movement. As the movement decreased, the core temperature also starts decreasing.

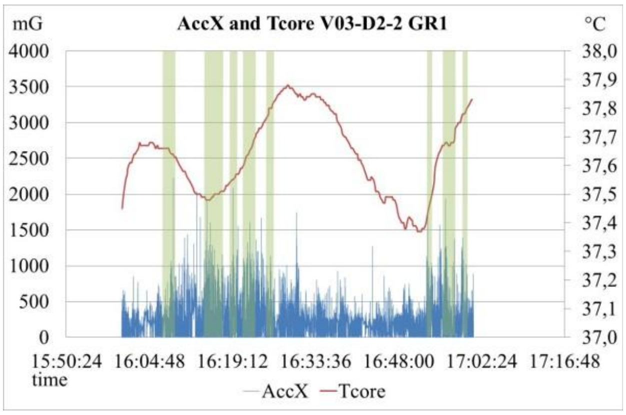


Figure 153 – Results for the volunteer 3 on day 2 afternoon, selected GR1 time period from 16:00 to 17:00 hours, lateral accelerometry (AccX) and core temperature variations.

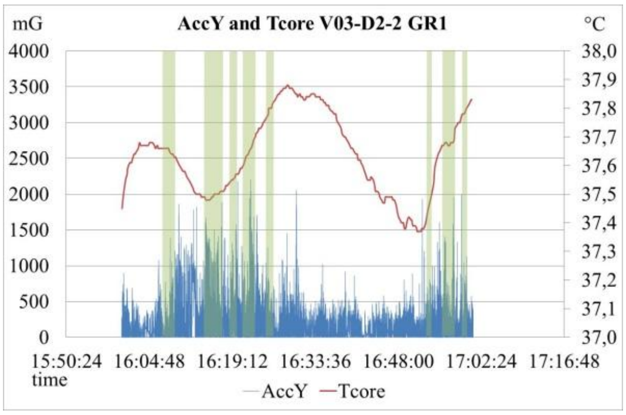


Figure 154 – Results for the volunteer 3 on day 2 afternoon, selected GR1 time period from 16:00 to 17:00 hours, longitudinal accelerometry (AccY) and core temperature variations.

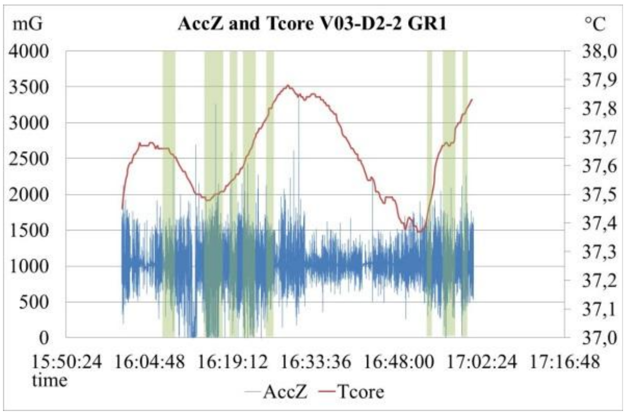


Figure 155 – Results for the volunteer 3 on day 2 afternoon, selected GR1 time period from 16:00 to 17:00 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figures 156-161 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 4 on day 3 morning. Periods within the severe cold chamber are marked by vertical green shaded areas, while periods within the severe hot thermal environment (outside) are marked with vertical purple shaded areas. On the left side axis in the first core temperature variations graph are illustrated values for the core temperature. On other graphs, on the left side axis are illustrated accelerometry values, while on the right side axis are illustrated the core temperature values.

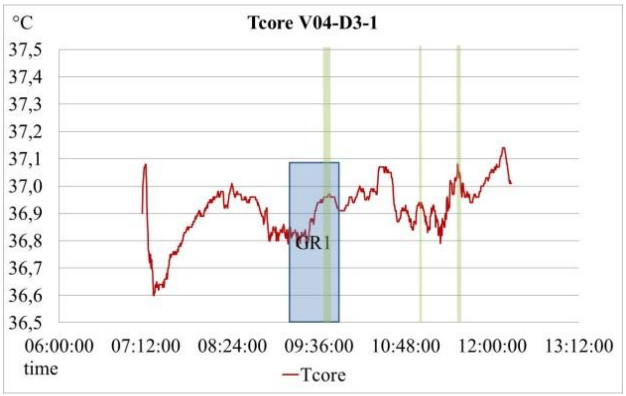


Figure 156 – Results for the volunteer 4 on day 3 morning, core temperature variations (the shaded blue area represent selected GR1 period).

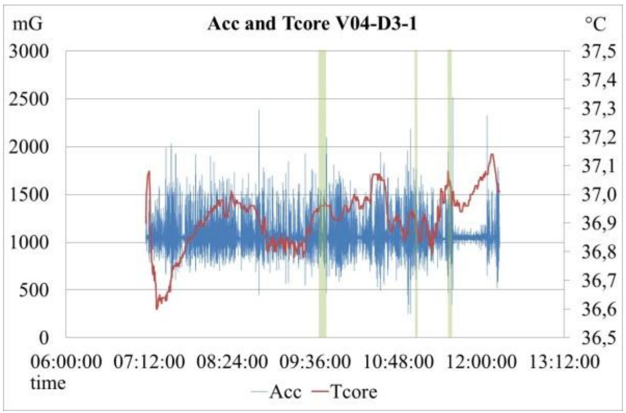


Figure 157 – Results for the volunteer 4 on day 3 morning, total accelerometry (Acc) and core temperature variations.

In the figure 157 is visible that the core temperature was increasing with increasing when the movement increased (accelerometry data) and decreased when the movement decreased, following the movement with a delay.

The shaded blue part on the figure 156 represent the part GR1 which was separately observed as occurred an increase in core temperature, and as the worker was exposed to SCE.

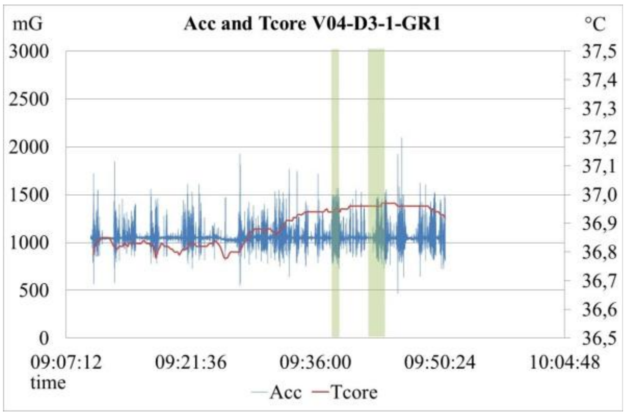


Figure 158 – Results for the volunteer 4 on day 3 morning, selected GR1 time period from 09:10 to 09:50 hours, total accelerometry (Acc) and core temperature variations.

In the figure 158, it is visible that the core temperature follows the increase and decrease in the movement. The core temperature was highest during SCE exposures.

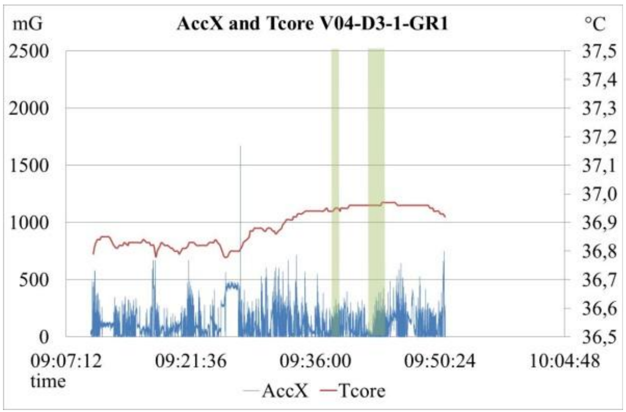


Figure 159 – Results for the volunteer 4 on day 3 morning, selected GR1 time period from 09:10 to 09:50 hours, lateral accelerometry (AccX) and core temperature variations.

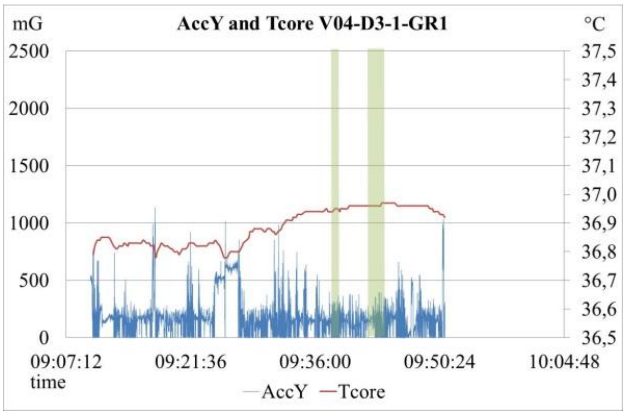


Figure 160 – Results for the volunteer 4 on day 3 morning, selected GR1 time period from 09:10 to 09:50 hours, longitudinal accelerometry (AccY) and core temperature variations.

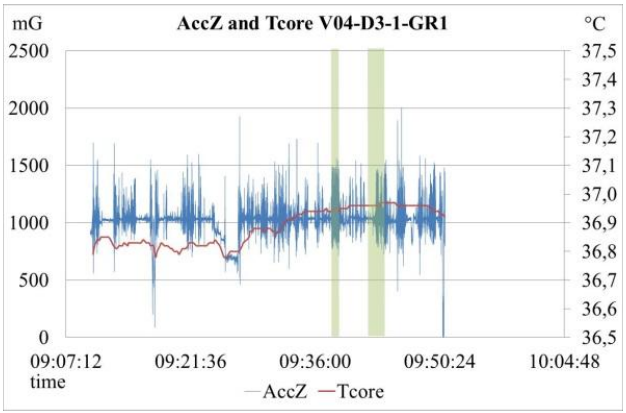


Figure 161 – Results for the volunteer 4 on day 3 morning, selected GR1 time period from 09:10 to 09:50 hours, vertical accelerometry (AccZ) and core temperature variations.

In the figure 162 are illustrated industrial results on accelerometry and core temperature data recorded for volunteer 4 on day 3 afternoon.

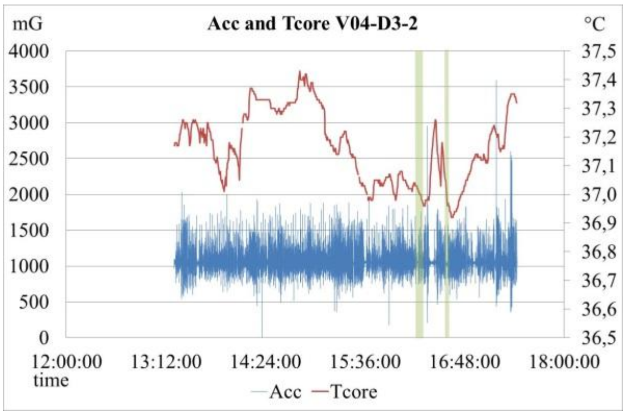


Figure 162 – Results for the volunteer 4 on day 3 afternoon, total accelerometry (Acc) and core temperature variations.

The shaded blue parts (GR1) were not selected for observing separately as no high increase or decrease in core temperature occurred during the workers exposure to SCE.

5.3 Discussion

5.3.1 Thermal sensation questionnaire (TSQ)

Although it seems that at the start of the afternoon working period male workers feel less cold compared with the end of the afternoon working period, the gathered data don't seem to be in accordance with any of the other gathered data. The data seem not to be consistent enough to make further conclusions. An example is the females answer to question 1 where the answers are similar even with longer exposure to moderate cold.

5.3.2 Cold work health questionnaire (CWHQ)

As the industry is located in north-eastern Brazil, with constant high outdoor air temperatures throughout the year, and the work is done at constant low indoor air temperatures in the cold packing sector, there is a risk of "*a frigore*", the diseases favored by low temperature conditions, sudden changes of temperature change from hot to cold, high humidity and air currents. Some answers to the CWHQ might be related to the clinical forms of "*a frigore*":

- Fifteen workers reported respiratory symptoms - the respiratory system which may occur in rhinitis, pharyngitis, laryngitis, bronchitis, bronchopneumopathies and pneumonias;
- Five workers reported cardiovascular symptoms,
- Twelve reported symptoms related to peripheral circulatory disturbances
- Twenty four reported symptoms related to white fingers - the cardiovascular system are favored the obliterate endarteritis, coronary heart disease and hypertension;
- Fifteen workers reported symptoms related to musculoskeletal system - the musculoskeletal system in which may occur rheumatic fever, arthritis and lombosciatics;

Renal diseases may also occur - glomerulonephritis and neurological - neuritis and neuralgia (Lally 1992; Mitu and Leon 2011).

According to ISO 15743:2008 (ISO 15743 2008), due to the answers of the workers, detailed interviews should be conducted on cold sensitivity, cold urticaria, respiratory function, cardiovascular function, peripheral circulatory disturbances, Raynaud phenomenon, musculoskeletal symptoms and performance. The type of detailed interview should depend on answers of each worker individually.

In the figure 19, in all answers (whole body, fingers and toes) male workers show higher intensity of discomfort (feeling more uncomfortable) compared to females (figure 20), which could be explained with higher exposure of males to severe cold thermal environment; therefore it is reasonable to see more complains on the influence of cold on their health in the male population, as their work is including exposure to SCE. Although answers from female workers show that the whole body thermal sensation (with 50% feeling slightly unpleasant and 50% feeling pleasant) and the fingers thermal sensation (10% feeling unpleasant, 50% slightly unpleasant and 40% feeling pleasant) have high satisfactory rate, their answers on the thermal sensation of toes show higher intensity of discomfort (10% feeling very unpleasant, 30% feeling unpleasant, 60% feeling slightly unpleasant and no one feeling pleasant). It could be explained with their standing packing activity which involves low legs activity with their long exposure to moderate cold and occasional exposure to severe cold (when the doors of the severe cold chambers open). More complains were found in female workers on questions regarding headache named migraine, increased excretion of mucus from the lungs, very profound rhinitis, for the color of fingers to episodically change into white, and back or hip pain, which could be explained with their type of work (packing shrimps into packages using plastic gloves for hygienic reasons, but not having gloves for cold protection, and standing during all working period).

5.3.3 Fully monitored workers

The workers experienced big fluctuation in air temperatures along the working days between outdoor, usually with temperatures above 25ºC (table 14), and indoor environment with a temperature bellow 18ºC, which might result with AMI and stroke (Gill et al. 2013), therefore the workers should be controlled on regular basis and the risk should be managed and reduced (Näyhä 2002; Mitu and Leon 2011).

In the figure 34, there is visible one radical decreasing of hand temperature without the worker being exposed to severe cold thermal environment. In that case, the worker was touching the frozen food package in order to measure its temperature, but without using cold protecting gloves, which was found by previous studies to impair complex manual performance and interfere with the use of tools, thereby reducing work safety (Virokannas 1996b).

The hand and forehead where found to have the highest and most frequent fluctuation in skin temperature, which is reasonable as they were mostly not covered with the cold protective clothing. The lowest recorded forehead value was 18.6°C, while the average minimal value was 5.3±3.6°C lower than the maximal value. The lowest recorded hand value was 14.1°C, while the average minimal value was 10.4±4.9°C lower than the average maximal value.

The hand skin temperature recovery was fast (±2 min from 18.6 to 28.0<°C), but when exposed to cold air or touching cold products or material it also decreased fast (±2 min from ±28.0 to 18.0°C), making the changes of its temperature frequent, fast and with greater differences.

The mean skin temperature show some small changes along the time, but without great and fast decreasing or increasing of the mean skin temperature, with a maximal variation between the minimal and maximal recorded value in one case of 5.1°C along all the measuring working period, and an average of between 1.1 to 3.2°C difference among the workers along all the measured working period. According to previous studies with repeated exposures of 30 min to -

25.0˚C, it was found that the mean skin temperature was lower for -2.3 to -2.8˚C at the end of the trial compared with the baseline measurements (T. G. Kim et al. 2007).

The mean body temperature has no significant change along the working period. As it is shown in the table 15, on two occasions: for V01-D3-1 and V02-D2-1, the mean body temperature decreased slightly below 35.0°C (on the minimal measured values, 35.0°C and 34.9°C respectively). The current literature has described it as the start of the mild form of hypothermia (general freezing) which occurs when the body temperature decrease to 32.0-35.0°C, and appears with shivering, tachycardia, tachypnea and slowness of ideation and compensated dysarthria. On appearing of mentioned clinical features, the workers should start a rewarming process (Mitu and Leon 2011; Golant et al. 2008). Through the indicators of changes in the metabolic rate, rectal and skin temperature, previous studies concluded that it is possible to quantify the adaptation level, including local cold adaptation of the extremities (Savourey, Vallerand, and Bittel 1992). However, cold exposure is necessary to increase the cold tolerance and prevention of cold injuries (Harinath et al. 2005).

Previous studies (T. G. Kim et al. 2007; Ozaki, Nagai, and Tochihara 2001) conducted at -25.0˚C concluded that with the exposure of 20 to 30 minutes there is a decline in rectal core temperature in resting, lighter and heavier work (from -0.6 to -1.1˚C). In the present study measuring intra-abdominal core temperature, the core temperature seem to raise in most of the cases with the exposure to severe cold (as illustrated in all graphics), which could be explained by the vasoconstriction in the superficial layers of the body (Charkoudian 2010). From graphs 15 and 16 (showing total accelerometry), it was not found a clear correlation between the accelerometry variations and the variations in core temperature. Nevertheless, accelerometry always seem to increase with cold exposure (due to the type of activity which is conducted in severe cold chambers), which may also contribute to the increase in core temperature values. The core temperature variations were always less than 1°C difference between the minimum and maximum value, in the most of the cases between 37.0 and 38.0°C. Although according to ISO 9886, the core temperature in cold thermal environment should be always measured through oesophageal or intra-abdominal temperature, in order to be relevant for the assessment of thermal strain in cold thermal environment (ISO 9886 2004), only studies with rectal and tympanic temperatures were found. Although the time of exposure to cold and severe cold environmental conditions were different among the mentioned studies, ranging from -5.0˚C to -25.0˚C, it was in general concluded that core temperature was decreasing according to 6 studies (7 articles) (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; Oksa et al. 2004; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; Daanen 2009) and increasing according to 3 studies (Dragan Brajkovic and Ducharme 2006; D. C. E. Gavhed and Holmér 1998; T. T. Mäkinen et al. 2001). In the studies where the working activity was sitting, order picking or loading, the core temperature was decreasing, while in studies where the working activity was walking on a treadmill, the core temperature was increasing. As the core temperature in the “increasing core temperature articles” was measured rectally, the explanation might be found in the production of heat from the local muscles, for which are is directly affected, and therefore it is higher when the work is performed with the legs than when it is carried out exclusively with arms (ISO 9886 2004). By several included articles it was concluded that the rectal temperature was highest when the working activity was heavier (T. T. Mäkinen et al. 2001; T. G. Kim et al. 2007; Dragan Brajkovic and Ducharme 2006).

Thus, given the results obtained in the present study and the results of previous studies by other authors, it can be concluded that more studies should be conducted on the influence of severe cold on core and skin temperature variations, taking into account both genders, with more time of exposure to severe cold. Studies should be also conducted on the variations of core and skin temperature in moderate cold. In activities as the standing packing, which in this study is conducted only by female workers, there are a particular interest on fingers and toes, which were found to have more complains.

5.4 Limitations

Challenges were found in gathering answers on questionnaires, as the working procedure is very flexible and workers change their working environment depending on the need of the working process. Difficulties were found in transmitting the recorded data of the Bioplux skin temperature sensors. The equipment did not have the possibility of recording the collected data directly to the device, but only by Bluetooth with a maximal distance of 10 meters from the equipment to the computer. As the workers were constantly moving it was challenging to stay constantly on a distance of less than 10 meters from the subject, following them with a computer when they entered the chamber and staying close to them while conducting the working activities.

The number of subjects was limited to the number of workers present in the cold packing sector. One of the limitations was the exposure to severe cold as the activity conducted which varied in each worker.

In the factory sector where the activities were developed the thermometer was located at 7 meters height and not at the height where workers worked, so there is no real information on to which environmental temperature the workers were exposed in the moderate cold sector.

5.5 Conclusions

Cold work involves several adverse health effects, pose a risk for cardiovascular diseases and musculoskeletal complains and symptoms. Answers to the CWHQ increase concern on clinical forms of "*a frigore*", which could be expected due to high differences between outdoor and indoor temperatures. Detailed interviews should be conducted on cold sensitivity, cold urticaria, respiratory function, cardiovascular function, peripheral circulatory disturbances, Raynaud phenomenon, musculoskeletal symptoms and performance. Highest and most frequent fluctuations were found in the hand and forehead skin temperature. The mean skin temperature showed some small changes along the time, but without great or rapid changes. The mean body temperature showed no significant fluctuations along the working period, but in two cases decreased slightly below 35.0°C which in the current literature has been described as the start of the mild form of hypothermia (general freezing). The core temperature variations were always less than 1.0°C difference between the minimal and maximal value, in most of the cases between 37.0 and 38.0°C. The core temperature was found to increase when the subject was exposed to severe cold. This occurrence may be justified, in part, by vasoconstriction. However, as workers only went to the freezing chamber to do some activity, and with an intensity higher than that performed outside the chamber, as can be proved by the collected values of accelerometry, it can be concluded that the physical exertion also had a contribution to the increase in core temperature.

Further experiments should be conducted with a higher number of volunteers, greater exposure to severe cold thermal environment, having a bigger sample with same working activities, thermal environment and time of exposure.

5.6 Acknowledgments

This project was financially supported by the Erasmus Mundus "BE Mundus" project during the year 2015/2016. Many thanks to all the support from the Federal University of Pernambuco (UFPE) and to the University of Pernambuco (UPE). Special thanks to the Laboratory on Safety and Occupational Hygiene (LSHT) of the UPE, which contributed greatly for this project to be successfully conducted.

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6 LABORATORY EXPERIMENTS

Influence of severe cold thermal environment on thermal sensation, core and skin temperature variations in humans

ABSTRACT

Cold exposure is present in outdoor activities in high latitude environments and in various occupations, which influences the variations in core and skin body temperatures and affects the working performance, health and safety of the humans. The aim of this work is to evaluate the changes in thermal sensation, and some physiological parameters before, while and after exposure to severe cold thermal environment (SCE). By using the Thermal Sensation Questionnaire (TSQ), blood pressure equipment, thermometer telemetry capsule for measuring the intra-abdominal temperature and 8 skin temperature sensors a study was conducted on 12 non-acclimatized volunteers for 60 minutes at -20˚C. The results show variations in all measured parameters. The findings of this study show a decrease in skin temperatures and the recovery period for each measured point, and increase in body and core temperatures although exposed to SCE. Future studies in SCE should be conducted measuring oesophageal and intra-abdominal core temperature, using more skin temperature measuring points, adding points in the extremities (face, fingers and toes).

KEYWORDS: cold exposure; winter; blood pressure; heart rate; thermal sensation questionnaire

6.1 Methodology

6.1.1 General data

The experiments were conducted in the Laboratory for the Prevention of Occupational and Environmental Risks (PROA), University of Porto, Portugal. All the documents were in both English and Portuguese language, depending on the volunteer preference. The experiment was approved by the Ethics Committee of the University of Porto, approval number: 06/CEUP/2015. The medical examinations were conducted in Hospital São João, Porto, Portugal, on all participants in order to select volunteers which are healthy or/and don't have medical contraindication to the experiment, namely regarding to the heart diseases, vascular diseases, respiratory diseases, gastrointestinal diseases (in particular the diverticular disorder), intolerance to cold, cold urticaria, other forms of urticaria or angioedema, musculoskeletal alteration, allergies, illness history and medications currently taking. Additional medical examinations were selected whenever clinical doubts emerged. The volunteers were fully informed of all details of the experimental procedures, the nature and purpose of the experiment, as well as the possible discomforts and risks involved discomforts. A written consent to participate in the experiment was read and signed by all volunteers before the experiments started. The air temperature outside the climatic chamber was 18.0°C, and inside -20.0°C (SCE). The trial duration was 3 hours with 30 min of measurement before exposure to SCE for sitting activity, 60 min of exposure to SCE for protocol activities, and 90 min after exposure to SCE for sitting activity.

6.1.2 Participants

Twelve non-acclimatized male volunteers were selected (mean±sd): age 24.50±3.37 years old, mean body height 178.59±4.53 cm, mean weight 79.13±6.17 kg, mean body mass index (BMI) 24.87±2.56 kg/m^2. The volunteers were all non smokers, didn't take any medicine, drank coffee, tea, alcohol and ate spicy food for at least 12h before the test. One additional volunteer (No. 6) was excluded due to being a cigarette smoker.

In the table 16 are illustrated physical characteristics and lifestyle data from laboratory subjects:

Table 16 – Detailed physical characteristics and lifestyle data from laboratory subjects.

Volunteer	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m²)	Right/Left handed	Smoker	Alcohol / Tea / Coffee / Medicine Spices food	Time of your last meal?	Ate for the last meal*	Went to sleep and woke up	Sleeping hours	Sports days/week?
LV01	24	180.9	73.10	22.34	Right	NO	0	07:10	Milk, bread, cookies	00:00 till 7:00	07:00	3
LV02	21	183.7	73.00	21.63	Right	NO	0	08:30	Yogurt, banana	01:00 till 8:40	07:40	2
LV03	28	168.9	87.10	30.53	Right	NO	0	23:00	Salad with chicken	23:40 till 7:50	08:10	0
LV04	26	174.2	69.30	22.84	Right	NO	0	08:00	Milk, bread	24:00 till 07:30	07:30	1
LV05	23	177.1	86.15	27.47	Right	NO	0	08:15	Milk, cereals	23:45 till 07:40	07:55	2
LV06						YES						
LV07	23	176.0	77.45	25.00	Right	NO	0	07:55	Oatmeal pancake	23:30 till 7:15	07:45	2
LV08	26	176.5	75.45	24.22	Right	NO	0	07:30	Milk, cereals, banana	00:30 till 7:20	06:50	0
LV09	33	178.5	78.50	24.64	Right	NO	0	08:20	Almond milk, bread	23:00 till 7:00	08:00	4
LV10	23	178.0	81.90	25.85	Right	NO	0	07:50	Scrambled eggs	00:30 till 7:45	07:15	5
LV11	21	185.0	77.80	22.73	Left	NO	0	07:15	Yogurt, bread, banana	1:30 till 7:00	05:30	5
LV12	23	181.3	89.50	27.23	Right	NO	0	22:30	Yogurt, bread, cookies	01:00 till 8:00	07:00	5
LV13	23	183.0	80.30	23.98	Right	NO	0	22:00	Beef, pasta	00:50 till 8:15	07:00	0

6.1.3 Equipment

The experiments were conducted in the climatic chamber Fitoclima 25000EC20. Skin temperature (Tskin) was measured with Bioplux skin temperature sensors. The sensors were put according to ISO 9886:2004 (ISO 9886 2004) on 8 measuring points: forehead (Sk8), right arm in upper location (Sk7), right scapula (Sk6), left upper chest (Sk5), left arm in lower location (Sk4), left hand (Sk3), right anterior thigh (Sk2) and left calf (Sk1). Core temperature (Tcore) was measured through intra-abdominal temperature with an Equivital Ingestible Pill Sensor (thermometer telemetry capsule) with dimensions of 8.7 mm by diameter and 23 mm by length. It was swallowed with water for at least 5 hours before each test (usually before going to sleep); travelled along the digestive tract harmlessly, and leaving naturally within 24 to 72 hours. The sensors began to transmit one minute after the capsule activation by the external monitor, sending details every 15 seconds to the EQ02 Life Monitor - Electronics Sensor Module (SEM), which transmits the data via Bluetooth. The SEM was transported in a belt, recording the data from core body temperature, chest skin temperature, heart rate, respiratory frequency and accelerometry (Acc).

The systolic (Sys) and diastolic (Dys) blood pressure and heart rate (HR) were measured with OMRON M10-IT Intellisense Upper Arm Blood Pressure Monitor. It was measured on the left arm for three consecutive times with a pause between measurements of 15 seconds. The volunteer was seated and did not talk. The mean value of the systolic and diastolic pressure as the heart rate was recorded. In total, it was measured 6 times: 10 minutes before exposure to SCE; and 5, 15, 30, 60 and 90 minutes after exposure to SCE, leaving the climatic chamber.

6.1.4 General lifestyle questionnaire (GLQ)

Based on a systematic review, a general questionnaire was created in order to get some basic data on the volunteer’s characteristics and lifestyle. The questions included: the date of birth; profession; if the volunteer is a cigarettes smoker; if drank alcohol, coffee, tea or ate spicy food in the past 12 hours; how many hours before the experiment he ate his last meal; what he ate for his last meal; medications currently taking, even if it was a headache pill; when he went to sleep and woke up, as the number of sleeping hours; if they were right or left handed; how many times per week they normally do sports.

6.1.5 Thermal sensation questionnaire (TSQ)

The Thermal sensation questionnaire (based on the Annex B of the ISO 10551:199 (ISO 10551 1993)) was answered in total 10 times on each trial: 10 minutes before exposure to SCE; right after entering; after 20, 40 and 60 minutes of SCE; and 5, 20, 40, 60 and 90 minutes after exposure to SCE, leaving the climatic chamber. In order to facilitate the answering and not to take-off the gloves, the questionnaire was located on the window of the climatic chamber, and answered by showing to the researcher the number from -4 to +4 on the cardboard. Additionally to the ISO TSQ, the questions (Q) 6, 7 and 8 were added by the researchers, in order to get more feedback on the sensation of the volunteer. All questions were enclosed in the appendix file.

6.1.6 Clothing

The volunteers wore special cold protective equipment (jacket with a hood, trousers, boots and gloves) above their normal clothing (socks, underpants, undershirt, trousers, thinly long-sleeved shirt, and sweater). In the appendix photo 1 is illustrated the clothes the volunteers were wearing and by which order the sensors and clothes were put on them.

6.1.7 Experimental protocol

One week before the experiment was conducted, the research team met the volunteers for the first time, explaining the comprehensive detail and purposes of the study and possible risks of the participation, getting general and lifestyle information of the volunteers, scheduling the medical control and giving the instructional flyer to the volunteers with short explanation on the purpose, benefits, equipment which will be used, kind of food and drinks to consume and avoid and clothes to wear for each experimental session. After conducting the medical control and being sure the volunteers meet all the physical characteristics, the informed consent was read and signed and the experimental days were scheduled. One day before the experimental day the research team met the volunteers again, asking for health conditions changes which might have occurred. The core body temperature pill was given to the volunteers and an explanation was given on how and when to ingest the pill. The volunteers were reminded on all important information.

In the climatic chamber illustrated in the figure 163 and 164, there were four main points: A) the table on which each session started and ended, on which three standard A4 paper boxes were situated (each weighting 5 kg); one box with 12 crumpled papers; and two pairs of plastic bottles with glass balls inside them (each pair weighting 0.8 kg); B) one cabinet with three shelves on different levels (shelf 1 – 10 cm, shelf 3 - 80 and shelf 5 - 150 cm from the ground); C) one cabinet with two shelves on different levels (shelf 2 - 45 and shelf 4 - 115 cm); and D) part of the chamber with two papers taped on the wall: one with the experimental protocol in order to remind the volunteers about the tasks that follow; and the TSQ, as illustrated on figures 165, 166 and 167.

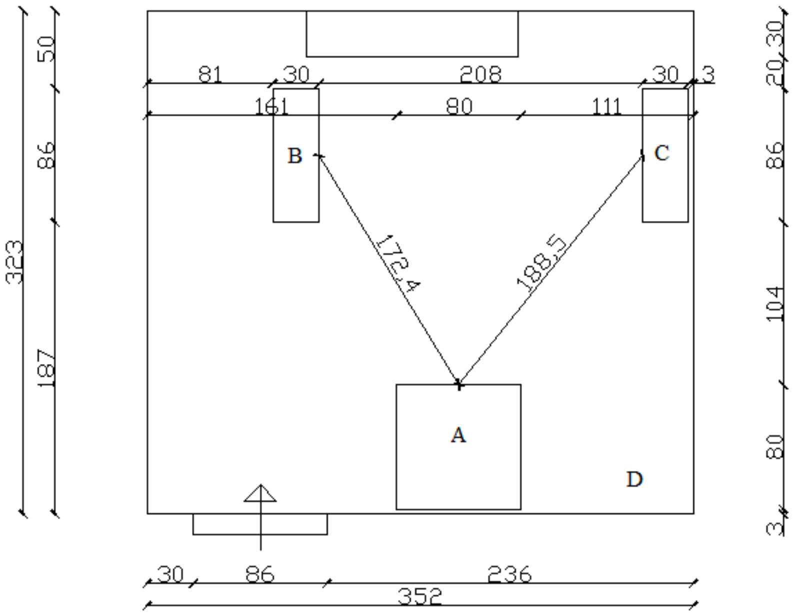

Figure 163 - The climatic chamber ground plan with dimensions in centimeters.

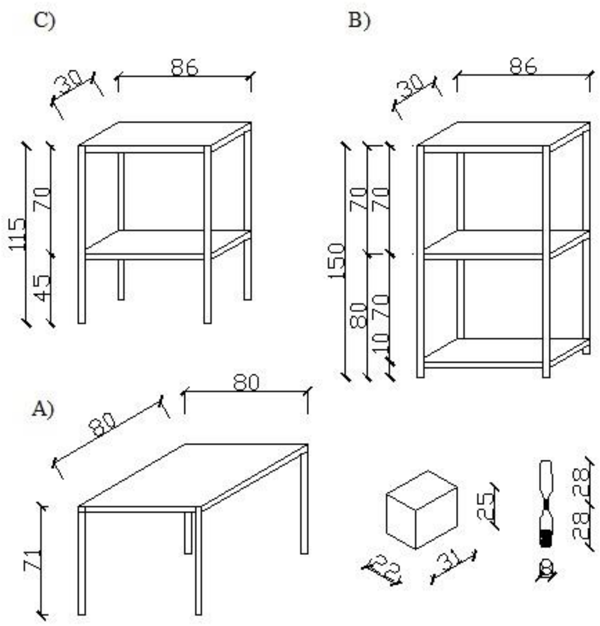

Figure 164 - Furniture A, B, C, box and bottle dimensions in centimeters.

The trials were aborted if: the volunteer felt any symptoms such as dizziness, nausea and general malaise; the core body temperature, measured by the sensors went lower than 36.0ºC (ISO 9886 2004); the local skin temperature (in particular for the extremities: face, fingers and toes) got to 15ºC (ISO 9886 2004).

It was conducted one trial per day, always at the same time, to minimize the influence of the circadian rhythm (Ozaki, Nagai, and Tochihara 2001). The volunteers were met at 09:15, and the core body temperature pill was checked in order to know if it is functioning and still inside the volunteer.

Figure 165 – The view on climatic chamber organization: on the left wall the protocol for the volunteer; on the window the TSQ; below the window the cardboards with a scale for answering the TSQ; on the right three boxes and 2 bottles for conducting the trial.

Figure 166 – The view on climatic chamber organization: on the left the cardboards with a scale for answering the TSQ; in the center the boxes and 2 bottles for conducting the trial.

Figure 167 – The view on climatic chamber organization: on the left wall the protocol for the volunteer; on the window the TSQ; below the window the cardboards with a scale for answering the TSQ.

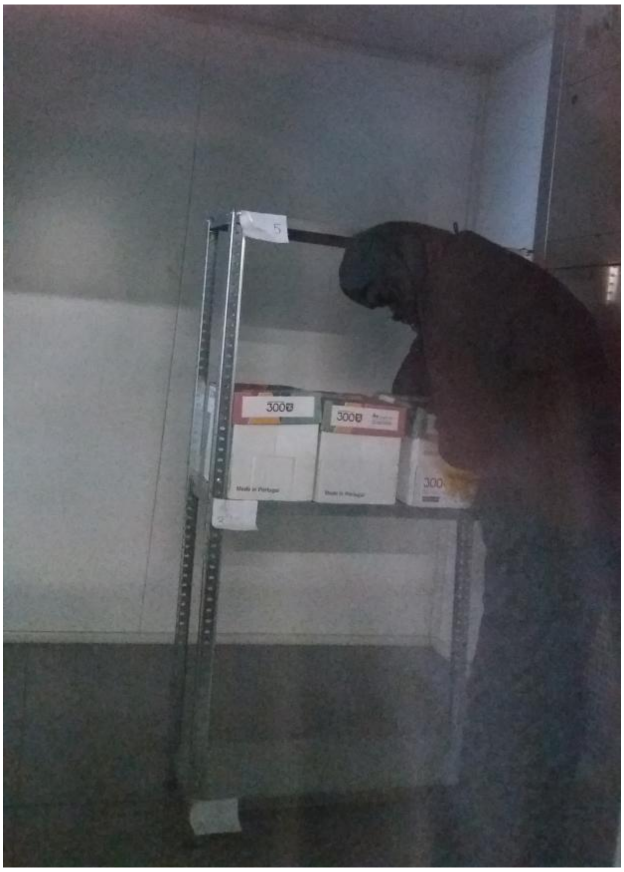

Figure 168 – The volunteer moving the boxes to position 3.

Figure 169 – The volunteer shaking 2 double bottles with glass balls of weight 0.4 kg each (till all the glass balls fall from the upper bottle down, repeating the process 10 consecutive times).

The temperature outside the climatic chamber was varying from 17.0 to 18.0°C. Then their height and weight were measured leaving just the underpants on them. Their body was cleaned with alcohol on all points where the skin temperature sensors were put and taped. After putting the sensors, they dressed the Equivital core body temperature belt. Afterward they dressed back up with socks, long sleeved trousers, a t-shirt and long sleeved shirt and all wires were put in one small handbag in order for them to feel more comfortable and protect the wires from braking. The equipment was turned on and the recording started for 30 minutes before they entered the climatic chamber and the experimental trial of 3 hours began as illustrated in table 17. Afterward they sat down and fulfilled the general lifestyle questionnaire and the experimental protocol was explained to them. Ten minutes before entering the climatic chamber, their BP, HR and TSQ answers were recorded. Five minutes before entering the climatic chamber they wore above all mentioned clothes the severe cold protective trousers, jacked with a hood, boots and gloves, leaving exposed just the part of their eyes, cheek and nose. Finally, they entered the climatic chamber.

Table 17 – Experimental trial.

Before SCE (±18°C)		**Exposure to SCE (± -20°C)**				**After SCE (±18°C)**				
Time (min)	30	60				90				
		Phase 1 20	Phase 2 20	Phase 3 20						
Activity	seated	exercise	exercise	exercise		seated				
TSQ (min)	10	0	20	40	60	5	20	40	60	90
9BP (min)	10	no measurements				5	15	30	60	90

Table 18 - One phase of the experimental protocol.

1	**Thermal sensation questionnaire**	**15**	**Do the game with glass balls 10x**
2	**Walk and heat up your hands (1min)**	**16**	**Rest 1 min (heat the hands)**
3	**Put four papers in each box (one by one)**	**17**	**Put the boxes from position 5 to position 4 (one by one)**
4	**Close the boxes**	**18**	**Rest 5 sec (heat the hands)**
5	**Put the boxes one by one to position 1**	**19**	**Put the boxes from position 4 to position 3 (one by one)**
6	**Rest 1 min (heat the hands)**	**20**	**Rest 5 sec (heat the hands)**
7	**Put the boxes from position 1 to position 2 (one by one)**	**21**	**Put the boxes from position 3 to position 2 (one by one)**
8	**Rest 5 sec (heat the hands)**	**22**	**Rest 5 sec (heat the hands)**
9	**Put the boxes from position 2 to position 3 (one by one)**	**23**	**Put the boxes from position 2 to position 1 (one by one)**
10	**Rest 5 sec (heat the hands)**	**24**	**Rest 1 min (heat the hands)**
11	**Put the boxes from position 3 to position 4 (one by one)**	**25**	**Put the boxes one by one to the table**
12	**Rest 5 sec (heat the hands)**	**26**	**Open the boxes**
13	**Put the boxes from position 4 to position 5 (one by one)**	**27**	**Put four papers from each box to the starting point (one by one)**
14	**Rest 1 min (heat the hands)**	**28**	**Walk and heat up your hands (1min)**

When entered the climatic chamber, they first turned on the speakers, as the music was provided in order to facilitate this one hour of exposure and activities. Afterward they followed the 20 minutes experimental protocol illustrated in figures 168, 169 and table 18, which was repeated for three consecutive times. The last 20 minutes phase ended with a TSQ.

When the volunteer exit the climatic chamber, he first un-dress the cold protective gloves, jacket and boots. Afterward he sat on a chair throughout the recovery period and his BP, HR and TSQ answers were recorded as explained previously.

The volunteer was not allowed to drink anything, go to the toilet or walk around till the trial finished. After 1.5 hour of recovery period, the skin and core temperature recordings were stopped, he was undressed, the equipment was removed and his body weight was measured again.

6.1.8 Data analysis

References were managed using the Mendeley 1.15.3. The core body temperature was recorded by using the Equivital Manager and EqView professional programs. The skin body temperature was recorded by using the MonitorPlux program, later on to be processed by using a Matlab 2014b software program. When the Tcore was -1˚C in the gathered data, it was considered as outlier and therefore excluded from the graphics. The mean skin temperature was calculated using the weighting coefficients as suggested by ISO 9886:2004 (ISO 9886 2004). Statistical analysis was done by using excel statistical toolbox.

6.2 Results

6.2.1 Blood pressure and heart rate

The results of the blood pressure and heart rate are illustrated in the table 19, showing the mean±sd, max and min values along the trial. The number of volunteers on which was measured varied as afterward it was decided to add more measurements in the trial. Blood pressure and heart rate for the first 5 volunteers were measured only 2 times (before and right after SCE), while for other volunteers it was measured 6 times.

Table 19 - Blood pressure and heart rate variations.

Measurement	Number of volunteers	12	12	7	7	7	7
	Time of measurement	Before SCE	After SCE				
		10 min	5 min	15 min	30 min	60 min	90 min
SYS BP (mmHg)	mean	116.18	119.67	119.14	117.86	111.71	113.71
	±sd	7.76	13.76	11.20	10.40	10.90	7.57
	max	127.00	146.00	134.00	130.00	126.00	128.00
	min	103.00	96.00	106.00	100.00	96.00	105.00
DYS BP (mmHg)	mean	74.64	69.00	71.14	70.57	72.43	73.14
	±sd	9.35	7.26	10.62	8.68	7.11	12.27
	max	91.00	77.00	85.00	78.00	79.00	86.00
	min	55.00	50.00	50.00	52.00	58.00	50.00
HR P/min	mean	62.73	71.08	70.00	66.86	66.43	62.29
	±sd	4.47	10.22	11.18	10.12	9.90	9.03
	max	71.00	92.00	86.00	79.00	77.00	75.00
	min	57.00	58.00	60.00	54.00	51.00	51.00

6.2.2 Thermal sensation questionnaire (TSQ)

The results of the TSQ are illustrated in the table 20, showing the mean, ±sd, max and min values along the trial. The number of volunteers varied for the same reason as for the blood pressure and heart rate measurements.

Table 20 - TSQ answers

Question	Number	12	12	12	12	12	12	11	11	11	8
	Time of measurement	Before SCE	While exposed to SCE				After SCE				
		10 min	0 min	20 min	40 min	60 min	5 min	20 min	40 min	60 min	90 min
1	mean	0.50	-1.25	-1.42	-0.92	-0.75	0.67	0.27	0.18	0.09	0.25
	±sd	1.00	0.97	1.00	1.38	0.97	1.07	0.65	0.40	0.30	0.71
	max	2.00	0.00	0.00	2.00	1.00	3.00	2.00	1.00	1.00	2.00
	min	-1.00	-3.00	-3.00	-3.00	-2.00	-1.00	0.00	0.00	0.00	0.00
2	mean	-0.08	-1.00	-1.17	-1.00	-1.08	-0.08	0.00	0.00	0.00	0.00
	±sd	0.29	0.43	0.83	0.74	0.79	0.29	0.00	0.00	0.00	0.00
	max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	min	-1.00	-2.00	-3.00	-2.00	-2.00	-1.00	0.00	0.00	0.00	0.00
3	mean	0.17	1.00	1.17	0.92	0.75	0.08	0.00	0.00	0.00	0.00
	±sd	0.58	0.95	1.03	1.08	1.06	0.29	0.00	0.00	0.00	0.00
	max	1.00	2.00	2.00	2.00	2.00	1.00	0.00	0.00	0.00	0.00
	min	-1.00	-1.00	-1.00	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00
4	yes	12.00	10.00	9.00	10.00	10.00	12.00	11.00	11.00	11.00	8.00
	no	0.00	2.00	3.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00
5	mean	-0.17	-0.75	-1.08	-0.92	-0.67	0.00	0.00	0.00	0.00	0.00
	±sd	0.39	0.75	0.79	0.79	0.89	0.00	0.00	0.00	0.00	0.00
	max	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	min	-1.00	-2.00	-3.00	-3.00	-3.00	0.00	0.00	0.00	0.00	0.00
6	sleepiness	0.00	0.00	0.00	0.00	0.00	0.00	1.00	4.00	5.00	5.00
	tiredness	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00
7	fingers	0.00	1.00	1.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00
	toes	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
8	feet	4.00	0.00	0.00	3.00	3.00	3.00	0.00	0.00	0.00	0.00
	fingers	0.00	2.00	5.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00
	nose	0.00	2.00	3.00	1.00	2.00	0.00	0.00	0.00	0.00	0.00
	chin	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
	toes	0.00	0.00	0.00	2.00	5.00	3.00	2.00	1.00	0.00	0.00

6.2.3 Core and skin temperatures (data of each volunteer separately)

In the figures 170-173 are illustrated results on skin and core temperature for laboratory volunteers 1. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines.

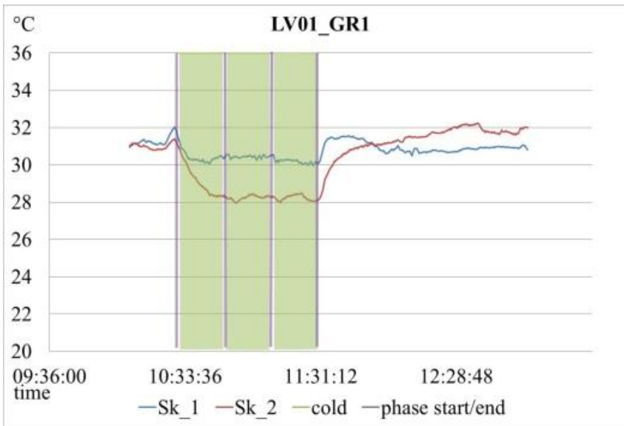

Figure 170 – Results for the laboratory volunteer 1, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

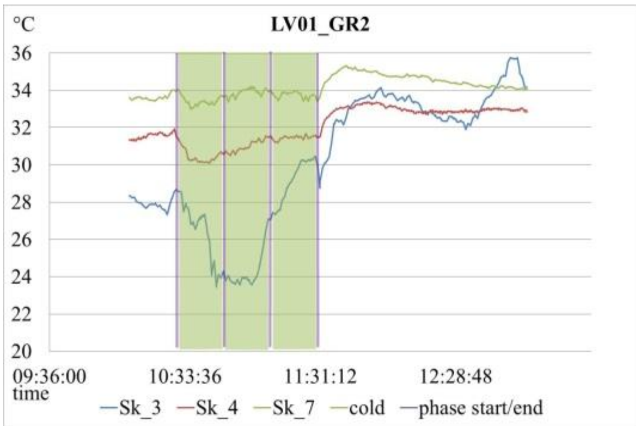

Figure 171 – Results for the laboratory volunteer 1, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈32.0 to 30.0°C during the first 5 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈31.5 to 28.0°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈29.0 to 24.0°C during the first 20 minutes of SCE exposure. Afterward it remained stable till 35 minutes of exposure, where it started increasing till the end of SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈32.0 to 30.0°C during the first 5 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈34.0 to 33.0°C during the first 5 minutes of SCE exposure. Afterward it started increasing, reaching the temperature before SCE exposure after 15 minutes, to remain stable until the end of SCE exposure.

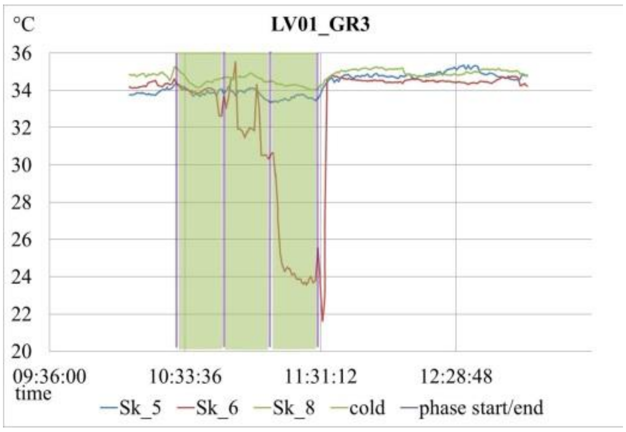

Figure 172 – Results for the laboratory volunteer 1, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

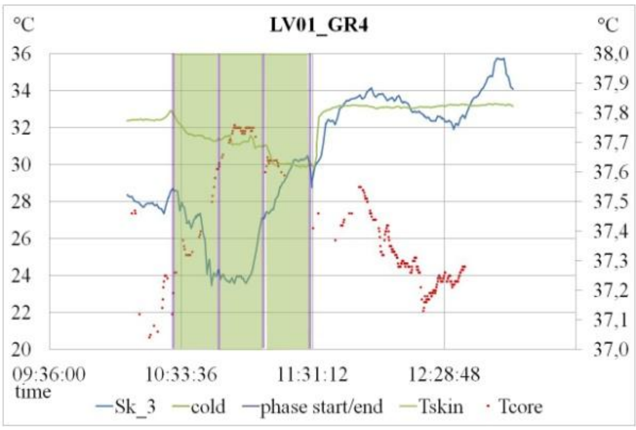

Figure 173 – Results for the laboratory volunteer 1, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) decreased slowly from ≈34 to 33.5°C till the end of SCE exposure, to increase only after SCE exposure.

The right scapula skin temperature (Sk_6) decreased when exposed to SCE. Afterward, it was noticed that the sensor untapped, which resulted in showing biased temperature. It increase only after SCE exposure.

The forehead skin temperature (Sk_8) decreased from ≈35.0 to 34.0°C during the first 10 minutes of SCE exposure. Afterward it had variations until the end of SCE exposure, to increase and stabilize only after SCE exposure.

The mean skin temperature (Tskin) continuously decreased till the end of SCE exposure, from ≈33 to 30°C, to increase only after SCE exposure.

The core temperature (Tcore) decreased during the first 5 minutes of SCE, afterward to increase from ≈37.3 to 37.75°C after 30 minutes of SCE exposure. Some core temperature data of this volunteer were not recorded, as there were problems with the equipment.

In the figures 174-177 are illustrated results on skin and core temperature for laboratory volunteers 2. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

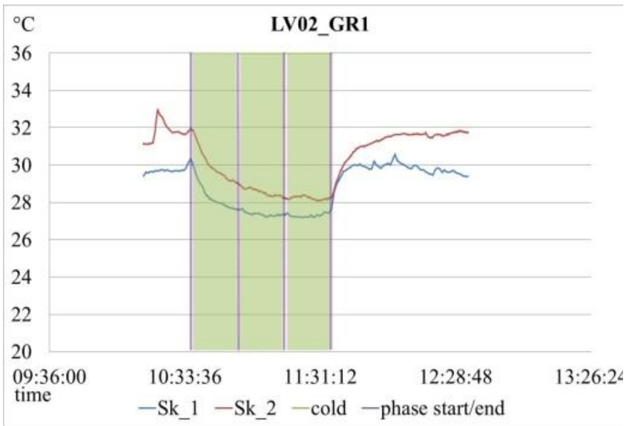

Figure 174 – Results for the laboratory volunteer 2, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

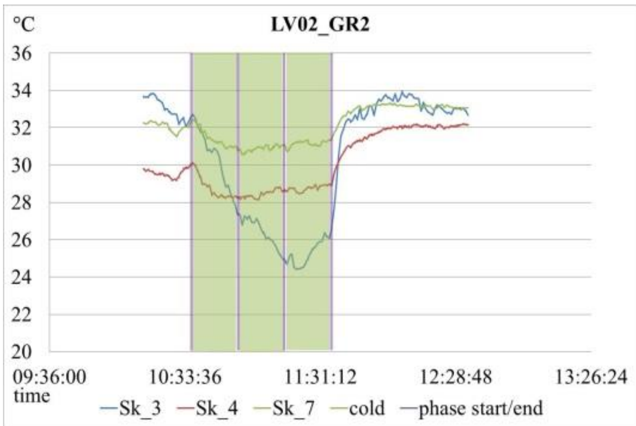

Figure 175 – Results for the laboratory volunteer 2, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈30.0 to 27.5°C during the first 30 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈32.0 to 28.0°C during the first 40 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈32.5 to 24.5°C during the first 40 minutes of SCE exposure. Afterward it started slowly increasing till the end of SCE exposure, and fast after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈32.0 to 31.0°C during the first 20 minutes of SCE exposure. Afterward it started slowly increasing till the end of SCE exposure, and fast after SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈30.0 to 28.0°C during the first 20 minutes of SCE exposure. Afterward it started slowly increasing till the end of SCE exposure, and fast after SCE exposure.

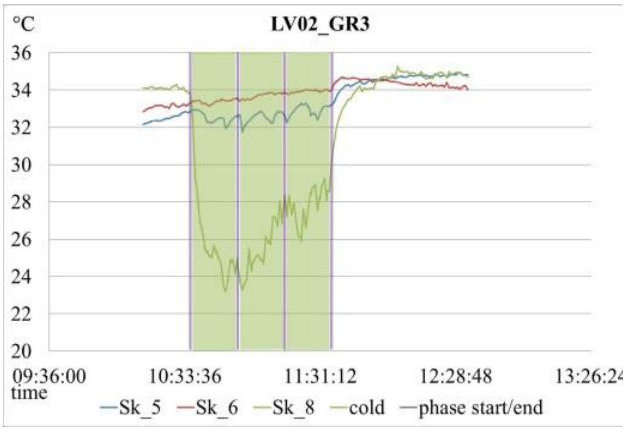

Figure 176 – Results for the laboratory volunteer 2, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

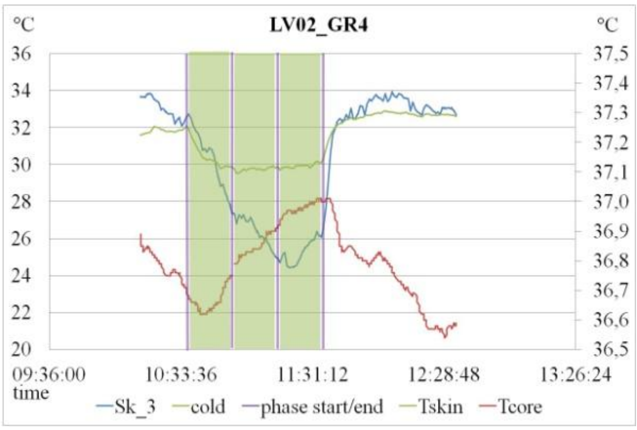

Figure 177 – Results for the laboratory volunteer 2, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) decreased and increased constantly throughout SCE exposure, reaching the temperature before SCE exposure of ≈33.0°C. After SCE exposure it continued to increase.

The right scapula skin temperature (Sk_6) slowly increased throughout SCE exposure from ≈33.0 to 34.0°C. After SCE exposure, it continued to increase.

The forehead skin temperature (Sk_8) decreased from ≈34.0 to 23.5°C during the first 15 minutes of SCE exposure. Afterward it started slowly increasing, reaching ≈29.0°C till the end of SCE exposure. After SCE exposure, it continued to increase.

The mean skin temperature (Tskin) decreased from ≈32.0 to 29.5°C during the first 20 minutes of SCE exposure, afterward to stabilize till the end of SCE exposure. Only after SCE exposure it started increasing.

The core temperature (Tcore) decreased during the first 7 minutes of SCE exposure from ≈36.7 to 36.6°C, afterward to increase to ≈37.0°C till the end of SCE exposure. The core temperature started decreasing after SCE exposure.

In the figures 176-181 are illustrated results on skin and core temperature for laboratory volunteers 3. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines.

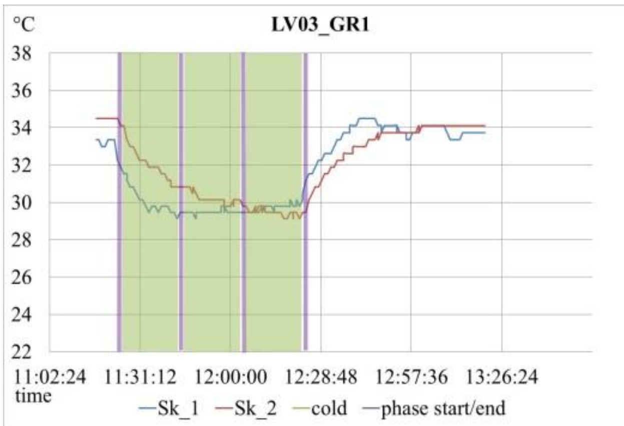

Figure 178 – Results for the laboratory volunteer 3, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

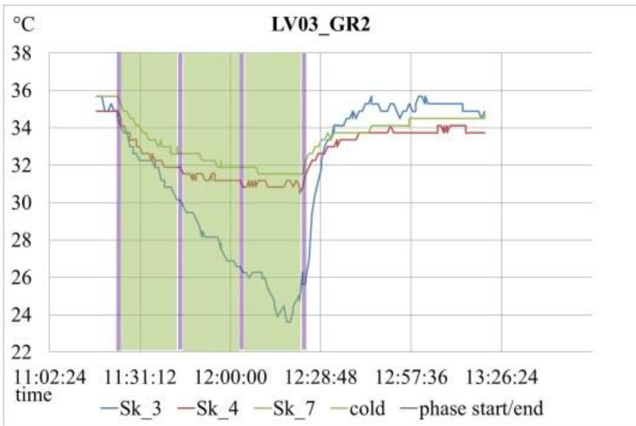

Figure 179 – Results for the laboratory volunteer 3, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈33.0 to 29.5°C during the first 10 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased continuously throughout SCE exposure from ≈34.5 to 29.5°C. After SCE exposure it started to increase.

The left hand skin temperature (Sk_3) decreased continuously throughout SCE exposure from ≈35.0 to 24.0°C. In the last minutes of SCE exposure it started to increase and continued to increase after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased slowly during the first 40 minutes of SCE exposure from ≈35.0 to 31.0°C. Afterward it stabilized, to increase only after SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased continuously during the first 45 minutes of SCE exposure from ≈35.5 to 31.5°C. Afterwards it stabilized, to increase only after SCE exposure.

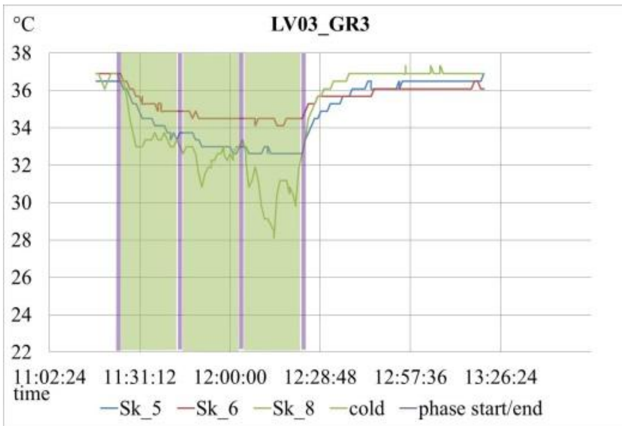

Figure 180 – Results for the laboratory volunteer 3, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

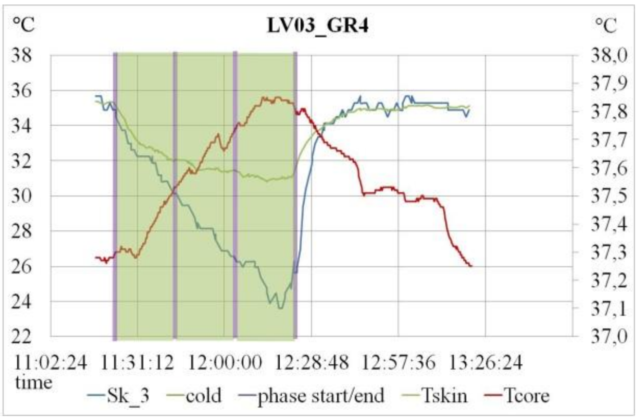

Figure 181 – Results for the laboratory volunteer 3, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) decreased continuously during the first 30 minutes of SCE exposure from ≈36.5 to 33.0°C. Afterward it remained stable, to increase only after SCE exposure.

The right scapula skin temperature (Sk_6) decreased from ≈37.0 to 34.5°C during the first 30 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The forehead skin temperature (Sk_8) decreased continuously with cycles throughout the SCE exposure from ≈37.0 to 28.0°C. Only after SCE exposure it started increasing.

The mean skin temperature (Tskin) continuously decreased during the first 40 minutes of SCE exposure from ≈35.5 to 31.0°C. Afterward it stabilized, to increase only after SCE exposure.

The core temperature (Tcore) increased throughout the SCE exposure from ≈37.3 to 37.75°C. After SCE exposure it started decreasing.

In the figures 182-185 are illustrated results on skin and core temperature for laboratory volunteers 4. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

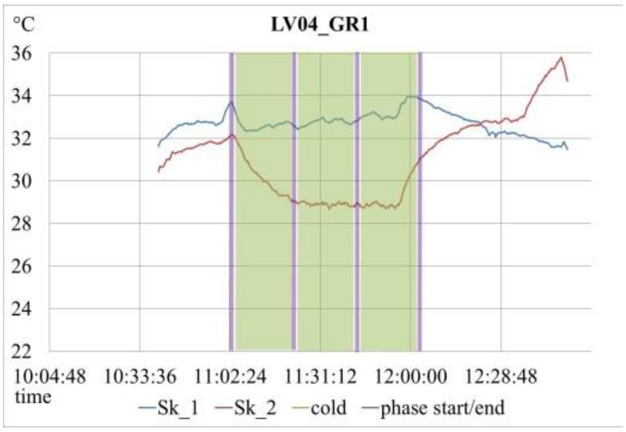

Figure 182 – Results for the laboratory volunteer 4, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

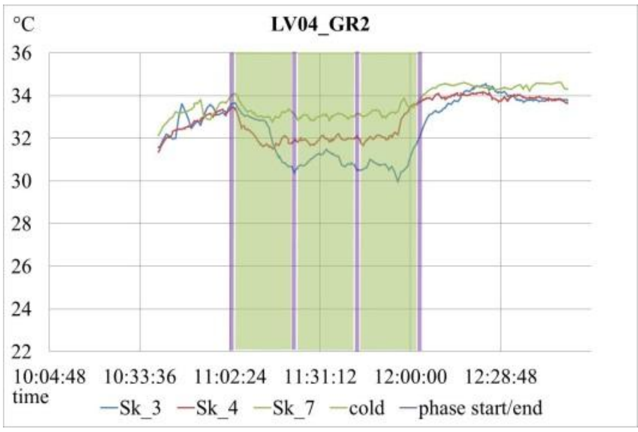

Figure 183 – Results for the laboratory volunteer 4, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈33.5 to 32.5°C during the first 5 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure, reaching the temperature before SCE exposure. After SCE, it started decreasing.

The right anterior thigh skin temperature (Sk_2) decreased from ≈32.0 to 29.0°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only few minutes before ending the SCE exposure, and continuing after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈33.5 to 30.0°C during the first 20 minutes of SCE exposure. Afterward it increased and decreased in cycles till the end of SCE, to increase only after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈35.5 to 31.5°C during the first 10 minutes of SCE exposure. Afterward it remained stable, to increase only 10 minutes before the end of SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈34.0 to 33.0°C during the first 10 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

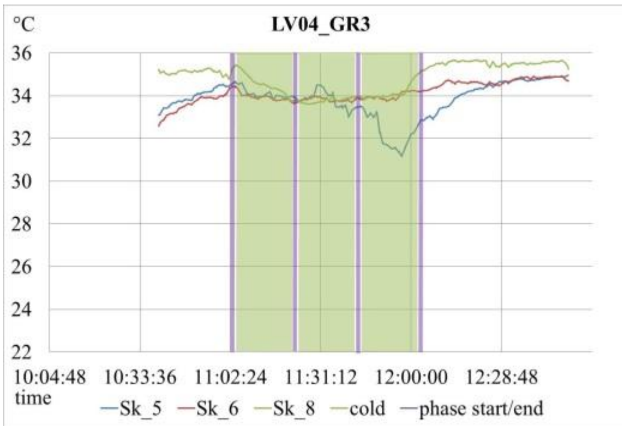

Figure 184 – Results for the laboratory volunteer 4, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

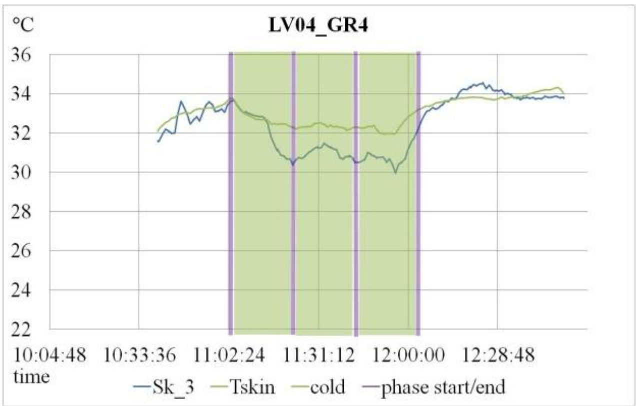

Figure 185 – Results for the laboratory volunteer 4, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) decreased slowly from ≈34.5 to 31.0°C till the end of SCE exposure, to start increasing only few minutes before the end of SCE exposure.

The right scapula skin temperature (Sk_6) remained stable throughout the SCE exposure, to increase only after SCE exposure.

The forehead skin temperature (Sk_8) decreased from ≈35.0 to 34.0°C during the first 20 minutes of SCE exposure, to start increasing only few minutes before the end of SCE exposure.

The mean skin temperature (Tskin) continuously decreased from ≈34.0 to 32.0°C till the end of SCE exposure, to start increasing only few minutes before the end of SCE exposure.

In the figures 186-189 are illustrated results on skin and core temperature for laboratory volunteers 5. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

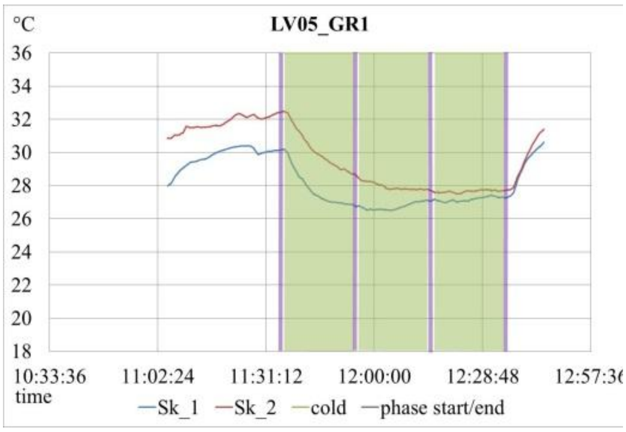

Figure 186 – Results for the laboratory volunteer 5, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

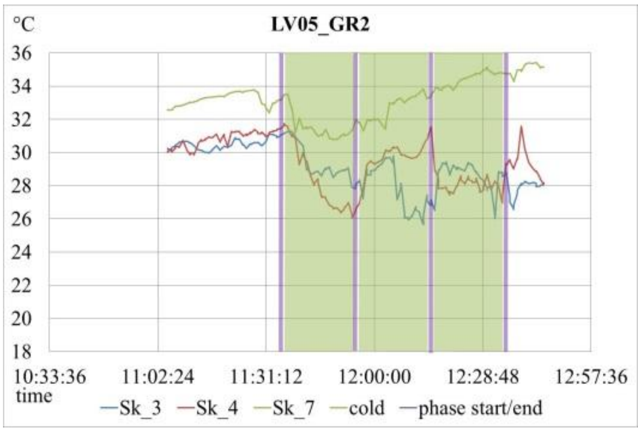

Figure 187 – Results for the laboratory volunteer 5, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈30.0 to 26.5°C during the first 20 minutes of SCE exposure. Afterward it started slowly increasing till the end of SCE exposure, to increase faster only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈32.5 to 28.0°C during the first 30 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased in cycles from ≈31.0 to 26.0°C during the SCE exposure. It stabilized after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈32.0 to 26.0°C during the SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈34.0 to 31.0°C during the first 10 minutes of SCE exposure. Afterward it started increasing, reaching the temperature before SCE exposure after 30 minutes and then continued to increase till the end of SCE exposure.

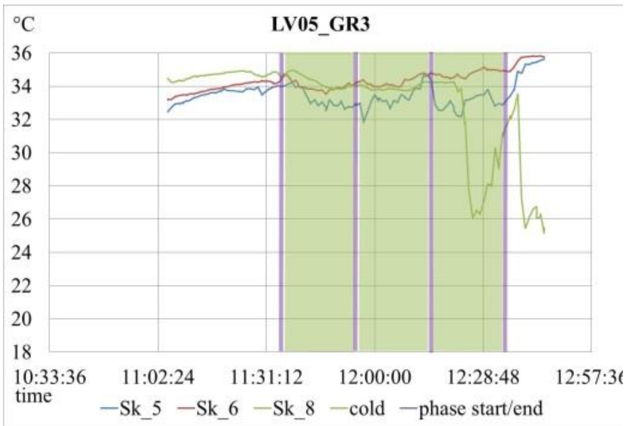

Figure 188 – Results for the laboratory volunteer 5, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations

Figure 189 – Results for the laboratory volunteer 5, left hand (Sk_3), Tskin and Tcore temperature variations

The left upper chest skin temperature (Sk_5) decreased slowly from ≈34.0 to 32.0°C during the first 20 minutes of SCE exposure. Afterward it increased and decreased in cycles till the end of SCE exposure. After SCE exposure it started increasing.

The right scapula skin temperature (Sk_6) increased slowly in cycles from ≈34.0 to 35.0°C till the end of SCE exposure. After SCE exposure it continued increasing.

The forehead skin temperature (Sk_8) decreased from ≈35.0 to 34.0°C during the first 50 minutes of SCE exposure. After 50 minutes of SCE exposure, the sensor untapped, resulting in a decrease of measured temperature.

The mean skin temperature (Tskin) continuously decreased in the first 20 minutes of SCE exposure from ≈33.0 to 30.0°C. Afterward it remained stable till the end of SCE exposure, and increased only after SCE exposure.

The core temperature (Tcore) decreased from ≈37.1 to 36.6°C during the first 5 minutes of SCE exposure, afterward to increase to ≈37.2°C till the end of SCE exposure, and continued to increase after SCE exposure.

The volunteer 6 was excluded from the data treatment as he was a cigarette smoker. In the figures 190-193 are illustrated results on skin and core temperature for laboratory volunteers 6. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines.

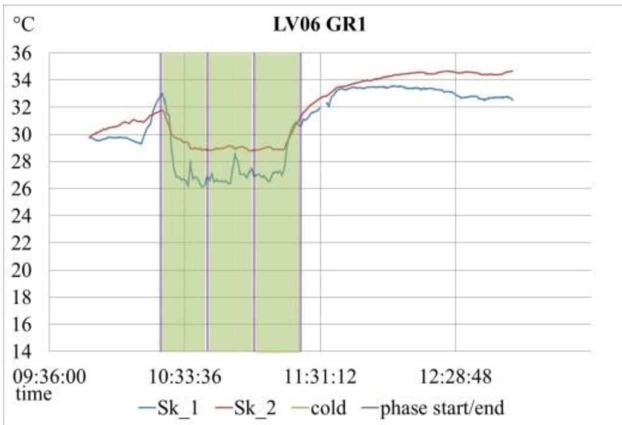

Figure 190 – Results for the laboratory volunteer 6, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

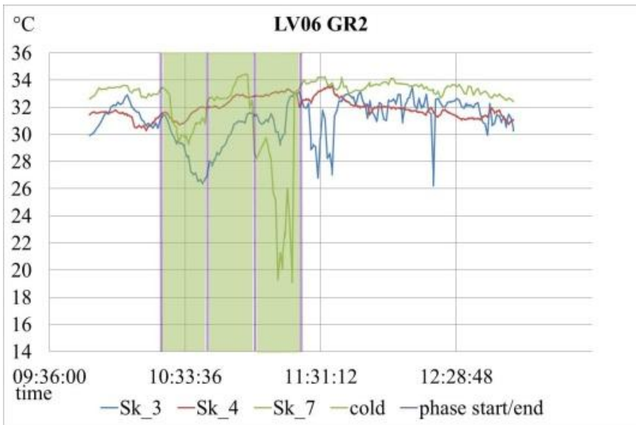

Figure 191 – Results for the laboratory volunteer 6, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈33.0 to 26.0°C during the first 10 minutes of SCE exposure. Afterward it increased and decreased in cycles throughout the SCE exposure, to increase only few minutes before the end of SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈32.0 to 29.0°C during the first 10 minutes of SCE exposure. Afterward it remained stable, to increase only few minutes before the end of SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈32.0 to 26.0°C during the first 20 minutes of SCE exposure. Afterward it increased and decreased in cycles throughout the SCE exposure and after SCE exposure.

The left arm in lower location skin temperature (Sk_4) increased throughout the SCE exposure from ≈32.0 to 33.0°C. Afterward it started slowly decreasing.

The right arm in upper location skin temperature (Sk_7) show a great decrease during the third phase of SCE, which can be related to the disconnection of the skin sensor.

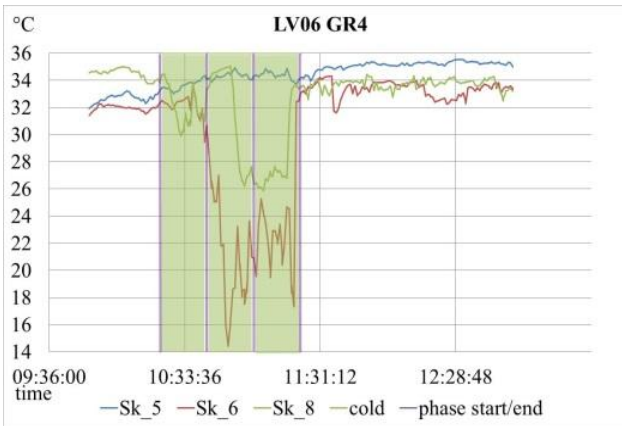

Figure 192 – Results for the laboratory volunteer 6, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

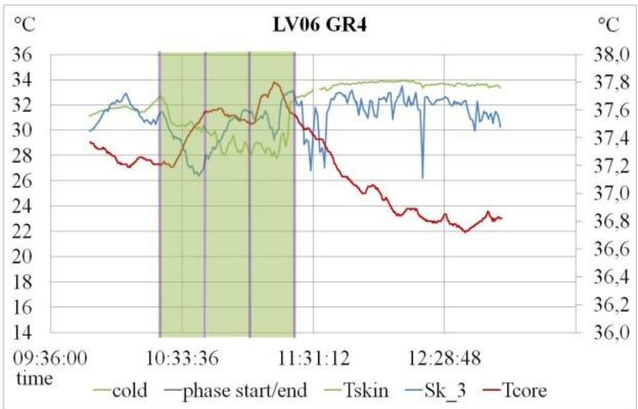

Figure 193 – Results for the laboratory volunteer 6, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) increased throughout the SCE exposure from ≈33.0 to 34.0°C. After SCE exposure it stabilized at ≈35.0°C.

The right scapula skin temperature (Sk_6) show a great decrease during second and third phase of SCE, which can be related to the disconnection of the skin sensor.

The forehead skin temperature (Sk_8) decreased in cycles from ≈34.0 to 26.0°C. Afterward it increased during the last phase of SCE exposure and remained stable after SCE exposure.

The mean skin temperature (Tskin) decreased from ≈32.5 to 28.0°C during the first 30 minutes of SCE exposure. Afterward it remained stable, to start increasing only a few minutes before the end of SCE exposure.

The core temperature (Tcore) increased in cycles throughout the SCE exposure from ≈37.2 to 37.8°C. In the end of SCE exposure it started decreasing, which continued after SCE exposure.

In the figures 194-197 are illustrated results on skin and core temperature for laboratory volunteers 8. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

Figure 194 – Results for the laboratory volunteer 8, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

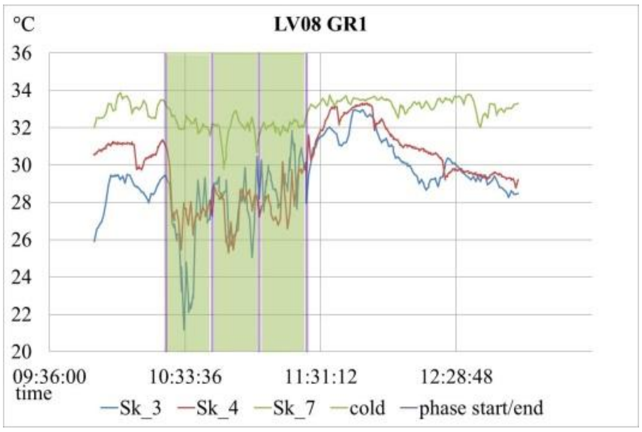

Figure 195 – Results for the laboratory volunteer 8, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈30.0 to 25.0°C during the first 20 minutes of SCE exposure. Afterward it started increasing until the end of SCE exposure and continued to increase faster after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈32.5 to 30.0°C during the first 40 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈29.0 to 21.0°C during the first 10 minutes of SCE exposure. Afterward it increased in cycles till the end of SCE exposure, continuing to increase after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈31.0 to 26.0°C during the first 5 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈33.5 to 30.0°C during the first 30 minutes of SCE exposure. Afterward it started increased and remained stable, to increase more only after SCE exposure.

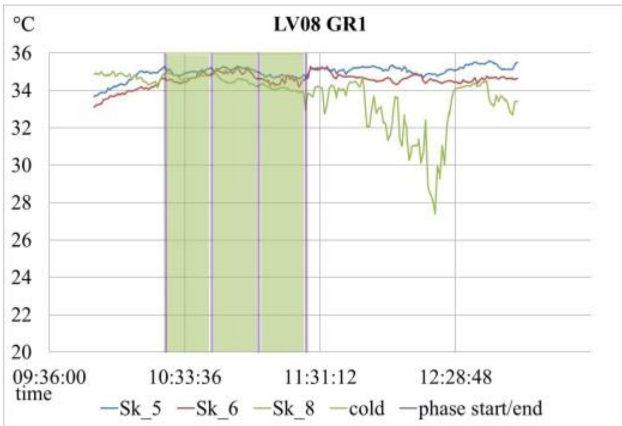

Figure 196 – Results for the laboratory volunteer 8, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

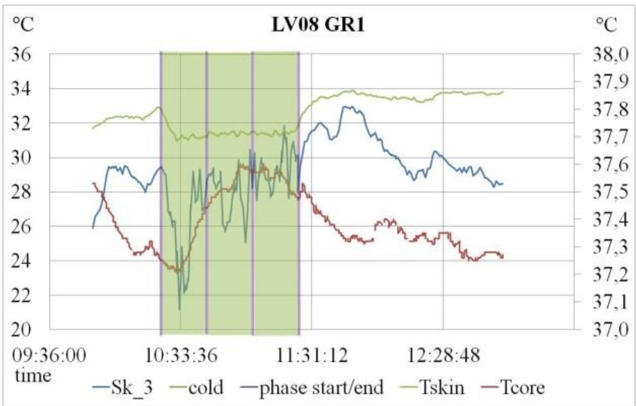

Figure 197 – Results for the laboratory volunteer 8, left hand (Sk_3), Tskin and Tcore temperature variations,

The left upper chest skin temperature (Sk_5) remained stable at ≈35.0°C throughout the SCE exposure and after it.

The right scapula skin temperature (Sk_6) remained stable at ≈35°C throughout the SCE exposure and after it.

The forehead skin temperature (Sk_8) decreased from ≈35.0 to 34.0°C during the SCE exposure.

The mean skin temperature (Tskin) decreased in first 10 minutes of SCE exposure from ≈35.0 to 31.0°C. It increased only after SCE exposure.

The core temperature (Tcore) decreased during the first 10 minutes of SCE, afterward to increase from ≈37.3 to 37.6°C after 40 minutes of SCE exposure. Afterward the core temperature starts decreasing.

In the figures 198-201 are illustrated results on skin and core temperature for laboratory volunteers 9. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

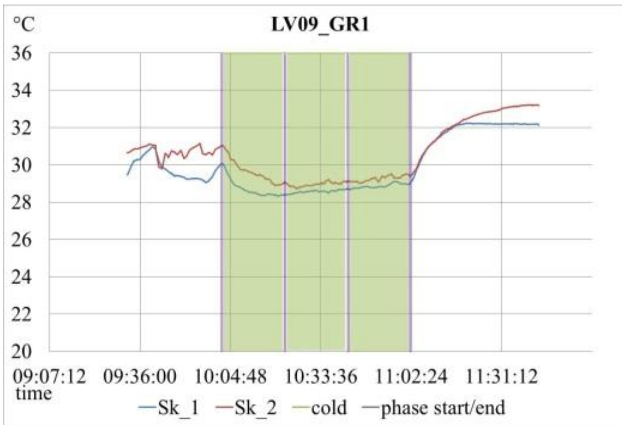

Figure 198 – Results for the laboratory volunteer 9, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

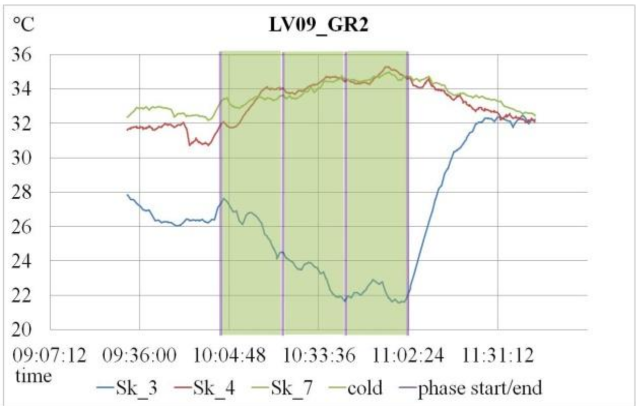

Figure 199 – Results for the laboratory volunteer 9, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈30.0 to 28.5°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈31 to 29°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈27.5 to 22.0°C during the first 40 minutes of SCE exposure. Afterward it increased only after SCE exposure.

The left arm in lower location skin temperature (Sk_4) increased throughout the SCE exposure from ≈32.0 to 35.0°C. After SCE exposure it started to decrease.

The right arm in upper location skin temperature (Sk_7) increased throughout the SCE exposure from ≈33.0 to 35.0°C. After SCE exposure it started to decrease.

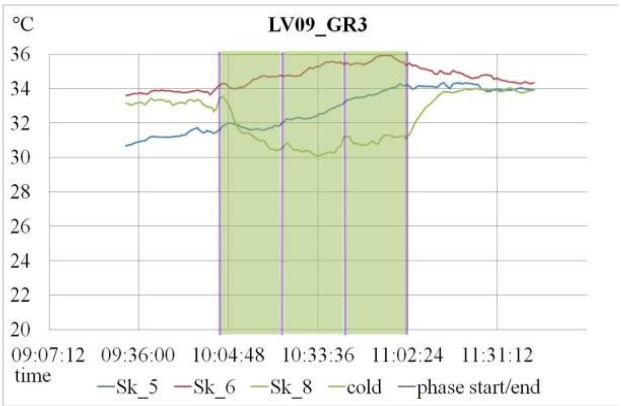

Figure 200 – Results for the laboratory volunteer 9, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

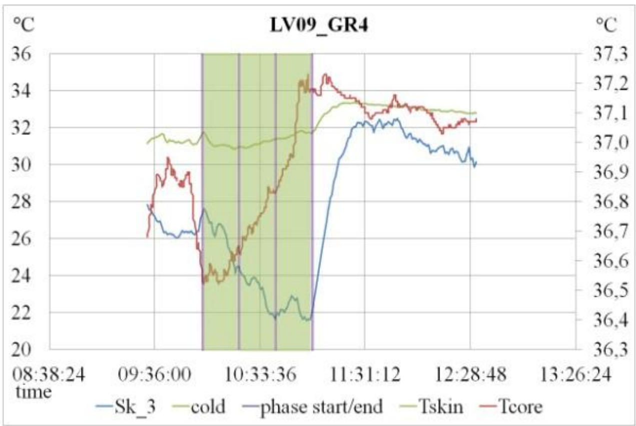

Figure 201 – Results for the laboratory volunteer 9, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) increased throughout the SCE exposure from ≈32.0 to 34.0°C. After SCE exposure it remained stable.

The right scapula skin temperature (Sk_6) increased throughout the SCE exposure from ≈34.0 to 36.0°C. After SCE exposure it started to decrease.

The forehead skin temperature (Sk_8) decreased from ≈34.0 to 30.0°C during the first 20 minutes of SCE exposure. Afterward it increased until the end of SCE exposure and continued increasing after SCE exposure.

The mean skin temperature (Tskin) decreased in first 5 minutes of SCE exposure from ≈32.0 to 31.0°C. Afterward it increased till the end of SCE exposure and continued increasing after SCE exposure.

The core temperature (Tcore) increased throughout the SCE exposure from ≈36.6 to 37.2°C. Afterward the core temperature starts decreasing.

In the figures 202-205 are illustrated results on skin and core temperature for laboratory volunteers 10. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines.

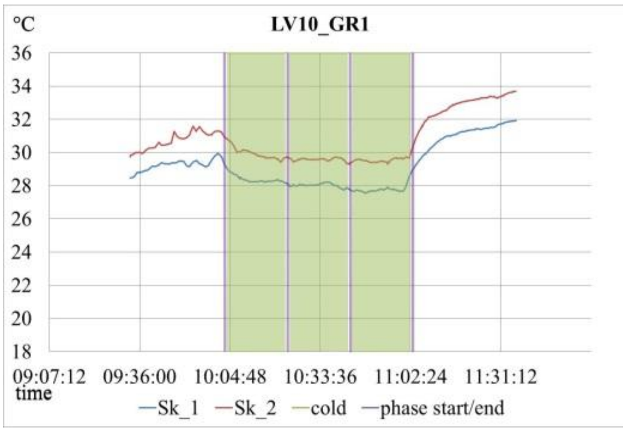

Figure 202 – Results for the laboratory volunteer 10, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

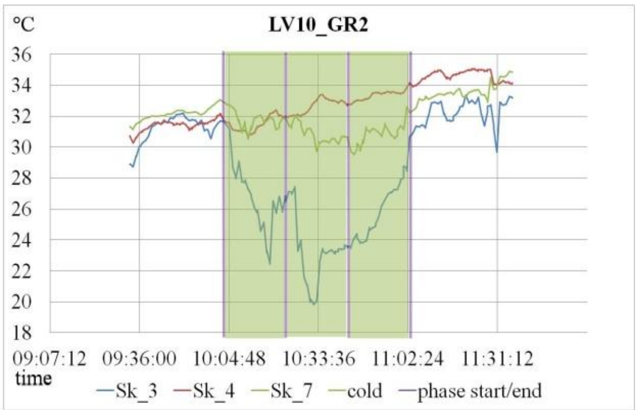

Figure 203 – Results for the laboratory volunteer 10, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈30.0 to 28.0°C during the first 10 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈31.0 to 29.5°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈31.5 to 20.0°C during the first 30 minutes of SCE exposure. Afterward it increased till the end of SCE exposure and continued increasing after SCE exposure.

The left arm in lower location skin temperature (Sk_4) increased throughout the SCE exposure from ≈31.0 to 34.0°C. After SCE exposure it continued increasing.

The right arm in upper location skin temperature (Sk_7) decreased during SCE exposure from ≈33.0 to 30.0°C. After SCE exposure it started increasing.

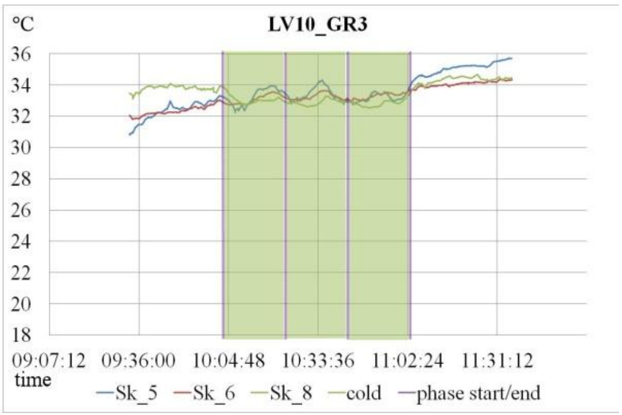

Figure 204 – Results for the laboratory volunteer 10, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

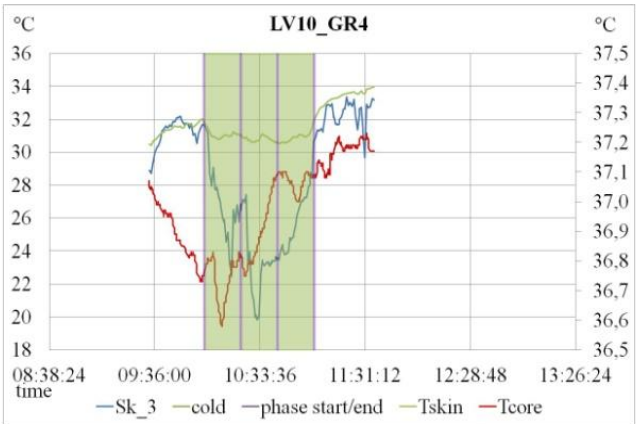

Figure 205 – Results for the laboratory volunteer 10, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) increased throughout the SCE exposure from ≈33.0 to 34.0°C. After SCE exposure it continued to increase.

The right scapula skin temperature (Sk_6) increased throughout the SCE exposure from ≈33.0 to 34.0°C. After SCE exposure it remained stable.

The forehead skin temperature (Sk_8) decreased from ≈34.0 to 33.0°C during the first 10 minutes of SCE exposure. Afterward it remained stable to increase only after SCE exposure.

The mean skin temperature (Tskin) decreased in first 5 minutes of SCE exposure from ≈32.0 to 31.0°C. Afterward it remained stable, to increase only after SCE exposure.

The core temperature (Tcore) decreased during the first 10 minutes, afterward to increase throughout the SCE exposure from ≈36.6 to 37.1°C, and continue increasing after SCE exposure.

In the figures 206-209 are illustrated results on skin and core temperature for laboratory volunteers 11. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

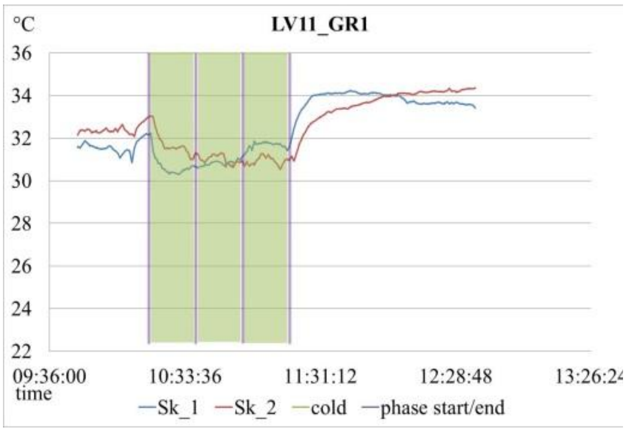

Figure 206 – Results for the laboratory volunteer 11, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

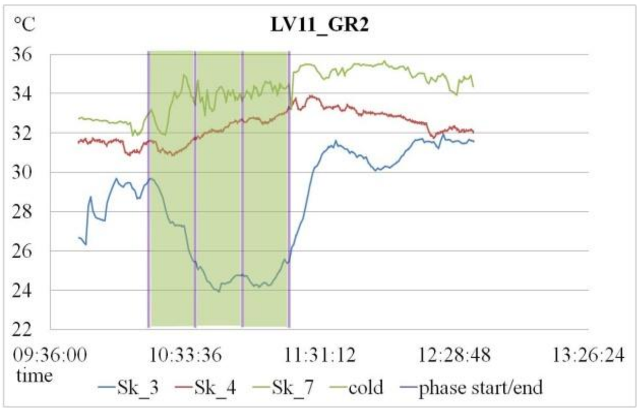

Figure 207 – Results for the laboratory volunteer 11, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈32.0 to 30.5°C during the first 10 minutes of SCE exposure. Afterward it started increasing until the end of SCE exposure, and continued increasing after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈33.0to 31.0°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈30.0 to 24.0°C during the first 30 minutes of SCE exposure. Afterward it started increasing until the end of SCE exposure and continued to increase after SCE exposure.

The left arm in lower location skin temperature (Sk_4) increased throughout the SCE exposure from ≈31.5 to 33.5°C. After SCE exposure, it started to decrease.

The right arm in upper location skin temperature (Sk_7) increased throughout the SCE exposure from ≈33.0 to 34.0°C. After SCE exposure, it remained stable.

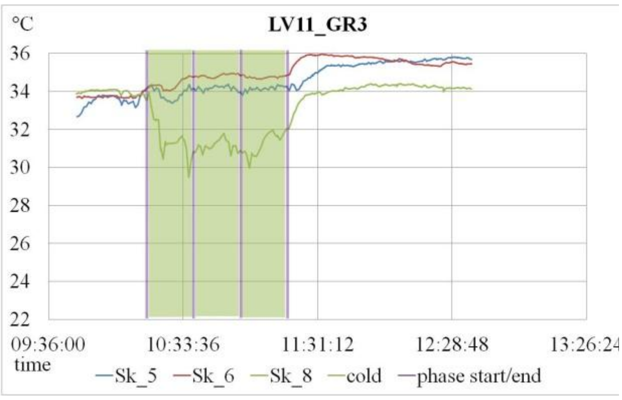

Figure 208 – Results for the laboratory volunteer 11, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

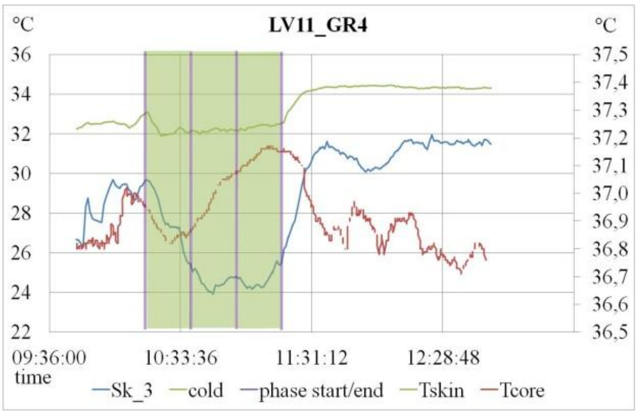

Figure 209 – Results for the laboratory volunteer 11, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) remained stable throughout the SCE exposure. After SCE exposure, it started increasing.

The right scapula skin temperature (Sk_6) increased throughout the SCE exposure from ≈34.0 to 35.0°C. After SCE exposure it continued to increase.

The forehead skin temperature (Sk_8) decreased from ≈34.0 to 30.0°C during the first 20 minutes of SCE exposure. Afterward it increased and decreased in cycles till the end of SCE exposure. After SCE exposure it started increasing.

The mean skin temperature (Tskin) decreased in first 5 minutes of SCE exposure from ≈33.0 to 32.0°C. Afterward it remained stable, to increase only after SCE exposure.

The core temperature (Tcore) decreased during the first 10 minutes, afterward to increase throughout the SCE exposure from ≈36.9 to 37.2°C. After SCE exposure it started to decrease.

In the figures 210-213 are illustrated results on skin and core temperature for laboratory volunteers 12. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

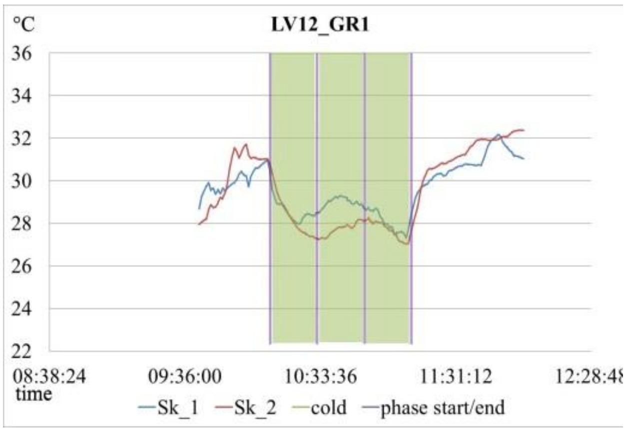

Figure 210 – Results for the laboratory volunteer 12, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

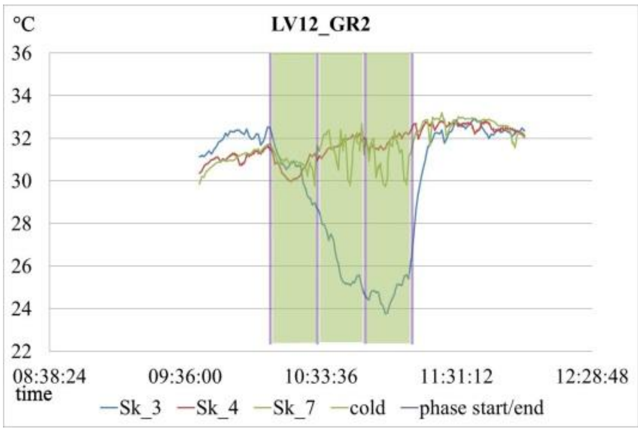

Figure 211 – Results for the laboratory volunteer 12, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈31.0 to 28.0°C during the first 10 minutes of SCE exposure. Afterward it increased and decreased in cycles till the end of SCE exposure, to increase only after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈31.0 to 27.5°C during the first 20 minutes of SCE exposure. Afterward it increased and decreased in cycles till the end of SCE exposure, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈32.0 to 24.0°C throughout the first 50 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈31.5 to 30.0°C during the first 10 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

The right arm in upper location skin temperature (Sk_7) increased and decreased throughout the SCE exposure. After SCE exposure it remained stable.

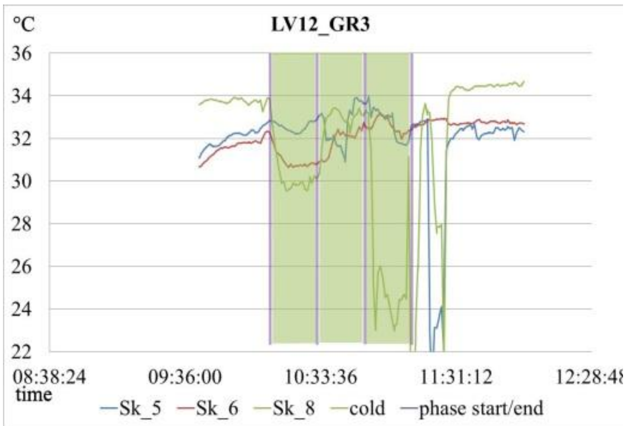

Figure 212 – Results for the laboratory volunteer 12, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

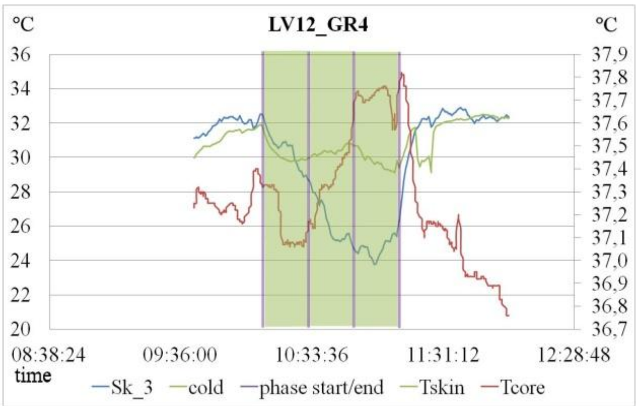

Figure 213 – Results for the laboratory volunteer 12, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) increased and decreased in cycles till the end of SCE exposure.

The right scapula skin temperature (Sk_6) decreased during the first 10 minutes of SCE exposure from ≈32 to 31°C and then started increasing until the end of SCE exposure. After SCE exposure, it stabilized.

The forehead skin temperature (Sk_8) show a great decrease during the third phase of SCE, which can be related to the disconnection of the skin sensor.

The mean skin temperature (Tskin) decreased in first 10 minutes of SCE exposure from ≈32.0 to 30.0°C. Afterward it remained stable, to increase only after SCE exposure.

The core temperature (Tcore) decreased during the first 10 minutes, afterward to increase throughout the SCE exposure from ≈37.1 to 37.8°C. After SCE exposure it started to decrease.

In the figures 214-217 are illustrated results on skin and core temperature for laboratory volunteers 13. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines:

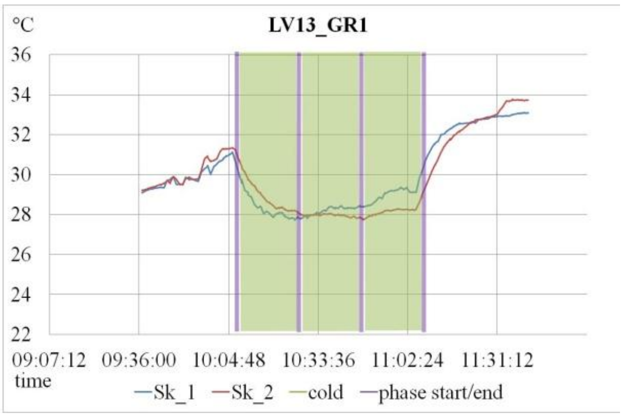

Figure 214 – Results for the laboratory volunteer 13, left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

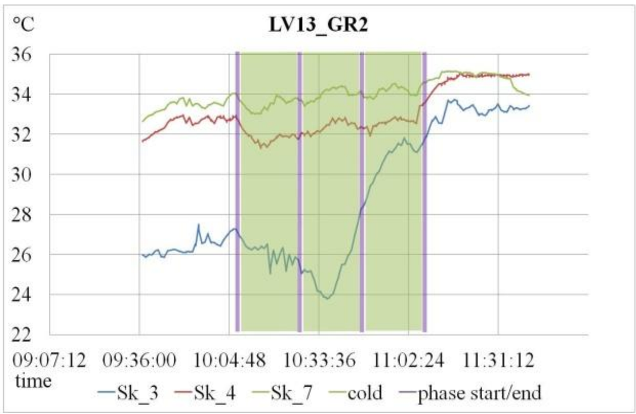

Figure 215 – Results for the laboratory volunteer 13, left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7) temperature variations.

The left calf skin temperature (Sk_1) decreased from ≈31.5 to 28.0°C during the first 10 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

The right anterior thigh skin temperature (Sk_2) decreased from ≈31.5 to 28.0°C during the first 20 minutes of SCE exposure. Afterward it remained stable, to increase only after SCE exposure.

The left hand skin temperature (Sk_3) decreased from ≈27.0 to 24.0°C during the first 30 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

The left arm in lower location skin temperature (Sk_4) decreased from ≈33.0 to 31.5°C during the first 10 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

The right arm in upper location skin temperature (Sk_7) decreased from ≈34.0 to 33.0°C during the first 10 minutes of SCE exposure. Afterward it started increasing till the end of SCE exposure and continued to increase after SCE exposure.

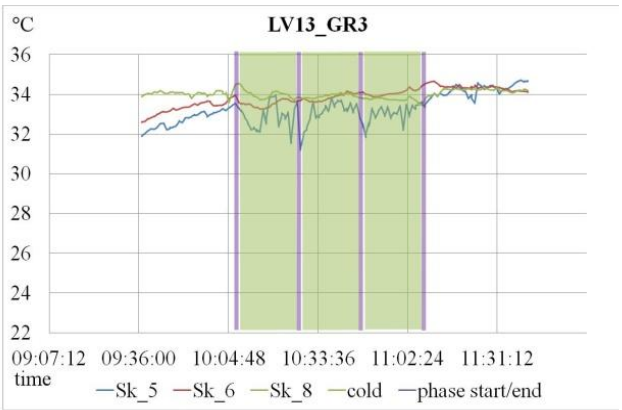

Figure 216 – Results for the laboratory volunteer 13, left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8) temperature variations.

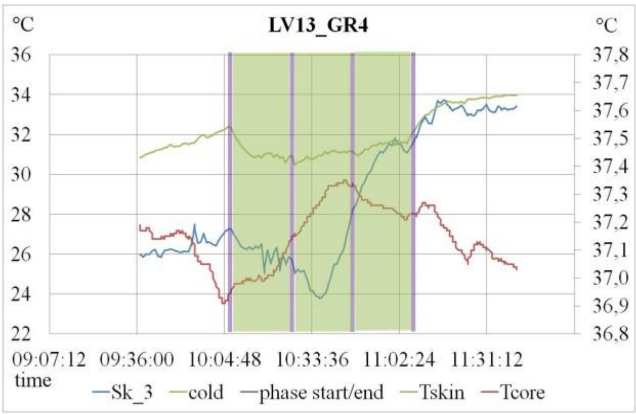

Figure 217 – Results for the laboratory volunteer 13, left hand (Sk_3), Tskin and Tcore temperature variations.

The left upper chest skin temperature (Sk_5) increased and decreased in cycles during all SCE exposure. After SCE exposure it remained stable.

The right scapula skin temperature (Sk_6) increased throughout the SCE exposure from ≈34.0 to 34.5°C. After SCE exposure it remained stable.

The forehead skin temperature (Sk_8) remained stable throughout the exposure and after exposure to SCE.

The mean skin temperature (Tskin) decreased in first 10 minutes of SCE exposure from ≈32.0 to 31.0°C. Afterward it remained stable, to increase only after SCE exposure.

The core temperature (Tcore) increased during the first 40 minutes of SCE exposure from ≈37.0 to 37.4°C. Afterward it started to decrease till the end of SCE exposure and continued to decrease after SCE exposure.

The left hand, forehead, Tcore, Tskin and Tbody temperature variations are illustrated in the table 21.

Table 21 - Mean, minimal and maximal temperatures along the trial.

TSQ time (min)		Trial time (min)		Left hand (˚C)	Forehead (˚C)	Tcore (˚C)	Tskin (˚C)	Tbody (˚C)
Before SCE	10	20	mean	29.91	34.27	37.02	32.14	35.51
			±SD	2.50	0.62	0.16	0.58	0.22
			min	26.36	33.33	36.77	31.20	35.15
			max	33.01	35.18	37.28	33.23	35.79
While exposed to SCE	20	50	mean	27.28	32.15	37.08	31.12	35.26
			±SD	2.15	2.90	0.32	0.83	0.39
			min	24.31	24.98	36.65	29.87	34.69
			max	30.49	34.84	37.62	32.26	35.88
	40	70	mean	26.10	32.72	37.29	32.10	35.42
			±SD	2.48	1.94	0.31	0.59	0.31
			min	21.64	28.08	36.83	31.31	34.80
			max	30.48	34.49	37.71	33.27	35.82
	60	90	mean	28.05	31.42	37.33	31.36	35.51
			±SD	3.21	4.10	0.29	1.13	0.29
			min	21.91	19.82	37.00	29.40	35.00
			max	32.10	35.11	37.83	33.16	35.81
After SCE	5	95	mean	30.24	33.19	37.31	32.64	35.87
			±SD	2.43	2.73	0.25	0.66	0.28
			min	25.04	25.45	36.96	31.50	35.48
			max	33.30	35.51	37.79	33.44	36.35
	20	110	mean	33.11	34.79	37.16	33.54	36.07
			±SD	1.10	0.90	0.25	0.79	0.38
			min	31.42	33.93	36.79	32.05	35.55
			max	34.89	36.90	37.63	34.77	36.77
	40	130	mean	32.57	34.48	37.12	33.64	36.04
			±SD	1.52	1.38	0.26	0.84	0.38
			min	30.20	31.42	36.69	32.43	35.49
			max	35.29	36.90	37.48	35.13	36.78
	60	150	mean	31.75	33.95	37.08	33.44	35.97
			±SD	0.88	0.96	0.24	0.68	0.25
			min	30.36	31.92	36.66	32.30	35.53
			max	33.06	34.84	37.33	34.28	36.24
	90	180	mean	30.59	33.85	37.01	33.29	35.92
			±SD	1.64	0.39	0.21	0.96	0.26
			min	28.47	33.40	36.71	32.22	35.63
			max	32.03	34.20	37.26	34.33	36.23

In the figures 218-221 are illustrated results of mean core and skin temperatures variations along the 3 hours trial period: 30 minutes before exposed to SCE, 60 minutes of SCE and 90 minutes after SCE. The results of the core temperature from V04 were not included in the calculations as core pill was excluded from the body before the experiment was conducted. The volunteer 6 was excluded from the data treatment as he was a cigarette smoker. The results of the skin temperatures from V07 were not included in the calculations as there were some problems with the txt data file and was not possible to analyze them. On the left side axis of the figures are illustrated skin temperature values with a scale from 25.0 to 35.0°C, while on the right side axis are illustrated core temperature values with a scale from 36.5 to 37.5°C. The vertical purple lines represent the phase start/end of the experimental protocol, while the vertical green the exposure to severe cold.

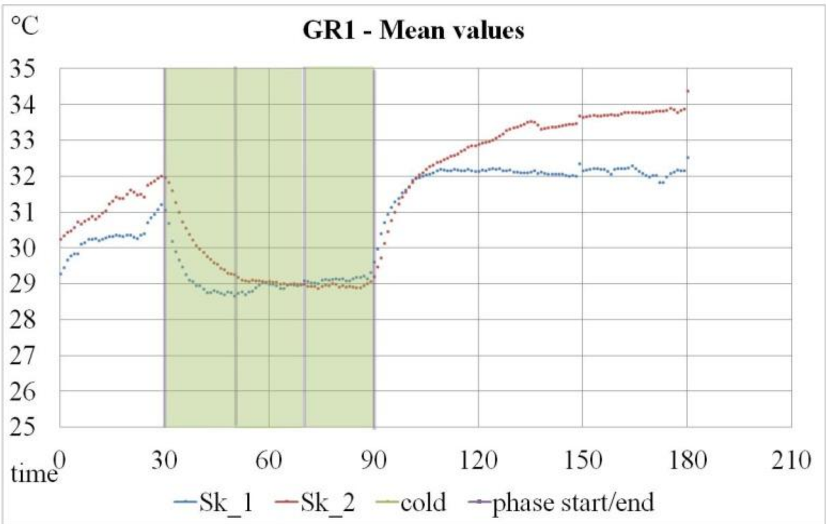

Figure 218 - Mean values of the left calf (Sk_1) and right anterior thigh (Sk_2).

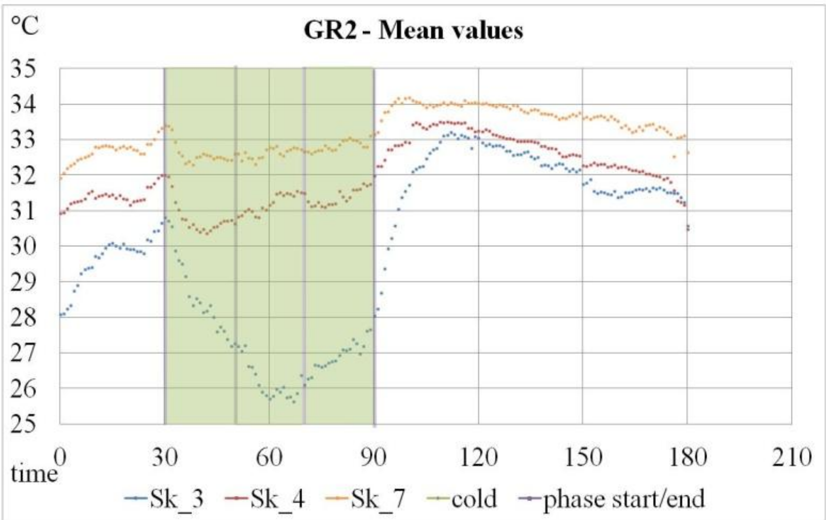

Figure 219 - Mean values of the left hand (Sk_3), left arm in lower location (Sk_4) and right arm in upper location (Sk_7).

Before SCE exposure there were two increases in all recorded skin temperatures. As the skin sensors were put on undressed volunteer, after his dressing, all skin temperature started increasing. Another increase occurred 10 minutes before SCE exposure, as the volunteer started dressing additional cold protective equipment.

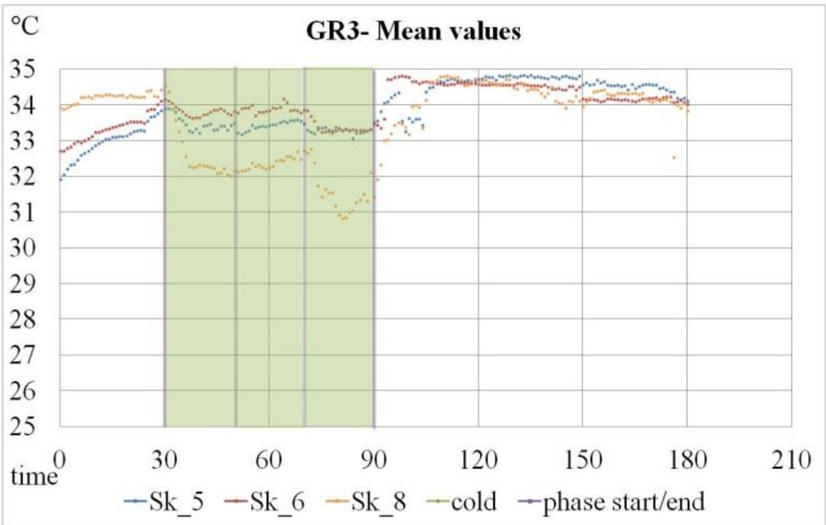

Figure 220 - Mean values of the left upper chest (Sk_5), right scapula (Sk_6) and forehead (Sk_8).

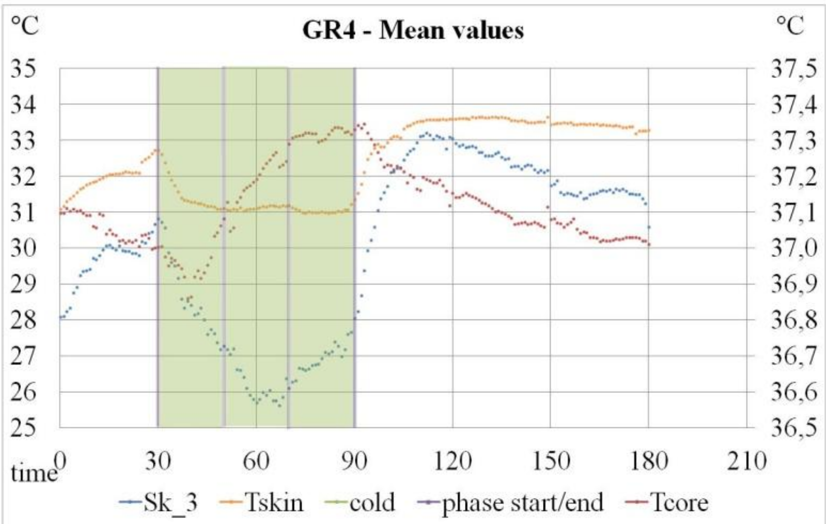

Figure 221 - Mean values of the left hand (Sk_3), Tskin and Tcore.

6.3 Discussion

6.3.1 Blood pressure and heart rate

To avoid misinterpretation of the data, the results from the first 5 volunteers were excluded from further analysis. The analysis of data from 7 volunteers measured 6 times, so that the systolic blood pressure increased from 116.18 mmHg (before SCE) to 119.67 mmHg (right after SCE), afterward to start decreasing below the initial value to 111.71 mmHg on 60 minutes after SCE.

The diastolic blood pressure decreased from 74.64 mmHg (before SCE) to 69.00 mmHg (right after SCE) and then it continues increasing and reaching 73.14 mmHg (90 minutes after SCE).

Compared with another study (Kluth, Penzkofer, and Strasser 2013) which measured blood pressure, found that through repeated exposure to severe cold (-24°C) conducting an order picking working activity of men, with a repeated cold exposure (20 min 20°C; 80 min -24°C; 20 min 20°C; 100 min -24°C; 20 min 20°C; 120 min -24°C; 20 min 20°C) found an increase of 15 mmHg systolic and 6 mmHg diastolic during working in cold compared with comfort temperatures. The systolic results gathered in our trial are lower than the results from the mentioned study, and the diastolic results show a decrease compared with the mentioned study. Nevertheless, fluctuations of ±10 mmHg (and more) that are unrelated to working in the cold are not uncommon (Kluth, Penzkofer, and Strasser 2013).

Twenty minutes after SCE, and when Tskin recovery, one volunteer started to feel sleepiness. After 40 minutes the number of volunteers increased to 4 feeling sleepiness.

The heart rate increased from 62.73 P/min (before SCE) to 71.08 P/min (right after SCE) and then it starts decreasing till the end, reaching 62.29 P/min (90 minutes after SCE). This could be related to the physical exertion which was conducted in the climatic chamber, and measuring HR after conducting the task. Previous study found that working in cold compared with comfort added additional 8 bpm for the younger and 3 bpm for the older subjects (probably because of 3kg more clothing in cold - higher physical strain) (Kluth, Penzkofer, and Strasser 2013).

6.3.2 Thermal sensation questionnaire (TSQ) and skin temperature

In the figure 222, the answers to question 1 (Q1), 2 (Q2) and 3 (Q3) of the TSQ seem to be in accordance with the Tskin before and while being exposed to severe cold. After 40 minutes of cold exposure there seem to be a psychological adaptation to cold and the answers to TSQ show higher thermal comfort. Although volunteers felt less cold (Q1 in figure 222), the Tskin remains low as during the first 40 minutes of SCE.

In the recovery period, after exposure to SCE, there is a faster stabilization in the thermal sensation compared with the physical parameters. In the first answers after SCE it is noticed that the volunteers answered to Q1 by feeling slightly warm, while the answers to Q2 and Q3 don’t anymore follow this answer, seem that although they feel slightly warm that they feel comfortable with it and don't want to feel cooler. This seems to be in accordance with the Tskin results which show that the body wants to recovery its skin temperature. When it comes to the stabilization of Tskin, the stabilization comes also for the answers Q1, Q2 and Q3.

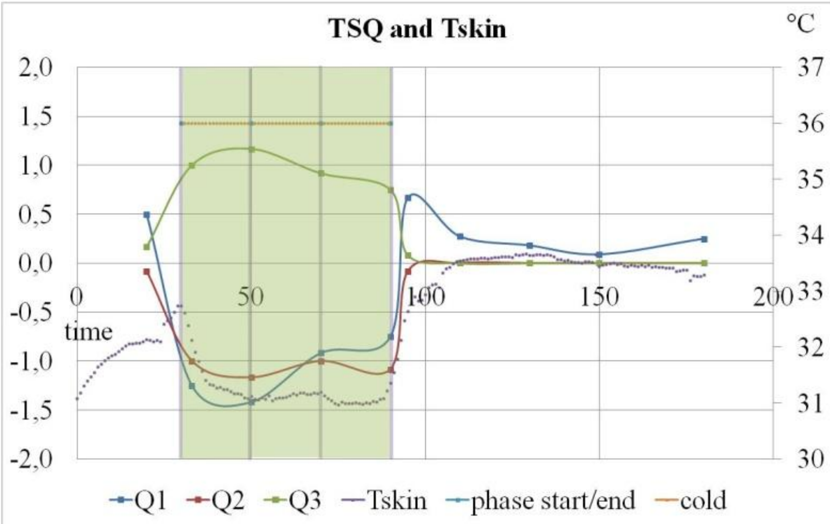

Figure 222 - TSQ answers to Q1, Q2 and Q3 and its comparison to Tskin variations.

On the left axis:

(Q1) Scale from -4 to +4: -4 (very cold), -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm), +3 (hot), +4 (very hot);

(Q2) Scale from -4 to 0: -4 (extremely uncomfortable), -3 (very uncomfortable), -2 (uncomfortable), -1 (slightly uncomfortable, 0 (comfortable);

(Q3) Scale from -3 to +3: -3 (much cooler),-2 (cooler), -1 (slightly cooler), 0 (neutral/without change), +1 (slightly warmer), +2 (warmer), +3 (much warmer).

In the figure 223 are illustrated the TSQ answers on fingers to Q7 (feeling pain) and Q8 (feeling cold) and the left hand (Sk_3) temperature variations. Some volunteers start feeling cold and pain particularly in the fingers although they have gloves protection. At the end of the first 20 minutes exposure phase half of them (6) reported to feel cold in fingers, while 3 of them feel pain (although the finger temperature was not measured, the hand temperature of those volunteers were not the lowest neither decreased faster, no difference was encountered compared with the other volunteers which didn't feel pain). The volunteers' cold and pain sensation on fingers start decreasing in the second phase and remains constant till the end of SCE. The reports on cold and pain sensations stop right after leaving SCE, while the left hand temperature recovery fast, it still continues growing even more than it was before the exposure. Increase in pain was following the increase in cold sensation (D. Gavhed et al. 2000).

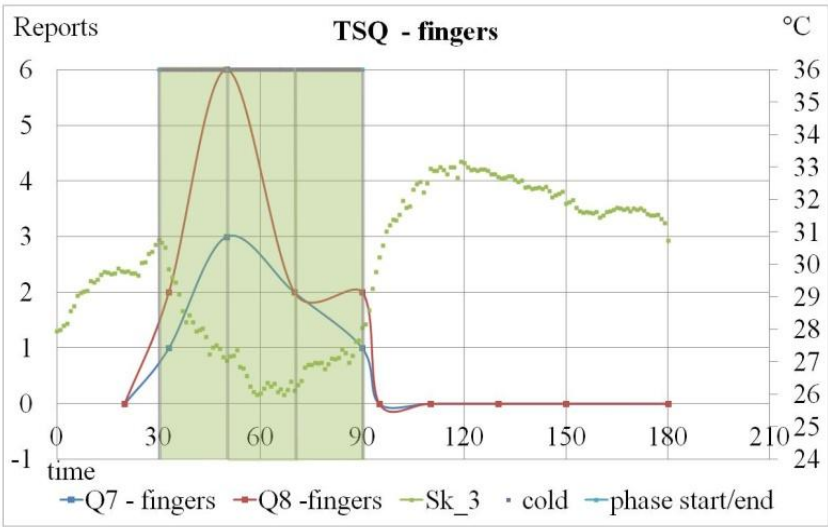

Figure 223 - TSQ answers to Q7 and Q8 on fingers sensation and a comparison with the left hand (Sk_3) temperature variations.

In the figure 224 are illustrated the TSQ answers on toes to Q7 (feeling pain) and Q8 (feeling cold) and the left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations. Although the cold and pain reports come already during the first minutes of exposure to SCE, the reports on cold and pain sensation come only after 40 minutes of exposure to SCE and it continues increasing till the end of the SCE exposure. As the skin temperature sensors were not put on toes, it is not possible to comment the relation between the toe temperature decrease and the cold and pain sensation. The cold sensation - although decreasing, persist in some volunteers even after 40 minutes of the recovery period. The pain sensation in toes was reported after 60 minutes of SCE and right after SCE, 5 min after the exposure, but afterward it does not persist.

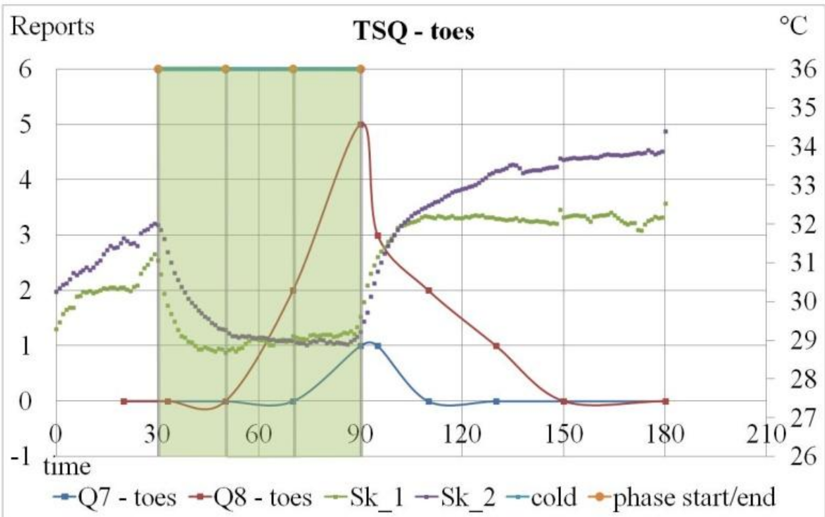

Figure 224 - TSQ answers to Q7 and Q8 on toes sensation and a comparison with left calf (Sk_1) and right anterior thigh (Sk_2) temperature variations.

During SCE, volunteers also reported feeling cold in feet, nose and chin. During the working period at SCE, some volunteers also reported tiredness.

Validated questionnaires should be created for the evaluation of cold thermal sensation. The thermal sensation questionnaire should also have questions related to cold and pain sensation of specific parts of the body with a scale.

6.3.3 Core and skin temperatures

As illustrated in the figures 218, 219, 220 and 221, all measured temperatures increased in the first 30 minutes of the trial. The reason was that the sensors were put on the volunteers without clothes, afterward they dressed normal clothes which resulted in increasing of their temperatures. Ten minutes before exposure to SCE, the volunteers put the cold protective clothes which resulted in the second increasing of their temperatures.

As illustrated in the figure 218, mean values of the left calf (Sk_1) and right anterior thigh (Sk_2) reached their lowest value after 20 minutes of SCE and maintained the nearly same value throughout the SCE exposure. The left calf although being on the lower part of the leg, reached a slightly lower temperature compared to the right anterior thigh, but it also recovered in the period of 20 minutes after SCE. The right anterior thigh (Sk_2) took more time to recovery and became stable only 1 hour after SCE.

As illustrated in the figure 219, mean values of the left arm in lower location (Sk_4) and right arm in upper location (Sk_7) lowered at the start of the exposure (left arm in lower location for 1.5°C and the arm in upper location for 1.0°C<, but throughout the exposure to SCE their temperatures increased till to the value before exposed to SCE. This could be related to the using of muscle groups while conducting the trial, therefore constantly heating them up (T. T. Mäkinen et al. 2001). The recovery period in this case finished at the end of SCE, but still it continued increasing for 10 minutes and then it remained stable.

As illustrated in figures 219 and 221, mean values of the left hand (Sk_3) had the biggest decrease of all measured skin temperature points. It decreased from 31.0°C to 25.5°C in the first 30 minutes of exposure to SCE. Afterward, it started slowly to increase which could be associated with more intensive manual hand heating. The temperature increased to 28.0°C till the end of the exposure to SCE. The hand temperature recovery period took 20 minutes (without gloves).

As illustrated in the figure 220, mean values of the left upper chest (Sk_5) and right scapula (Sk_6) decreased slightly during the exposure to SCE, but afterward remained stable at that temperature throughout the exposure period. The recovery period was 5 minutes after SCE. The forehead (Sk_8) had high temperature variations (highest after the left hand among the measured skin points). The temperature was decreasing throughout the exposure to SCE from 34.5 to 31.0°C. The recovery period was 20 minutes after exposure to SCE.

Results of the mean skin temperature show a decrease from 32.8 to 31.1°C in the first 20 minutes of exposure to SCE, which is not as low as a previous study conducted with a walking/jogging activity at -20.0˚C for 60 minutes, reported that skin temperature decreased to 27˚C. The study doesn't report initial skin temperature, just stating a decrease (Oksa et al. 2004).. Afterward Tskin had small variations, but always remaining around 31.1°C. After SCE, it took 20 minutes to recovery and come to a stable 33.6°C. In some volunteers was recorder a minimal value below 30°C (V01-29.84°C; V02-29.52°C; V12-29.12°C) which is in accordance with the previous study where the volunteers were sitting activity at -20˚C for 40 minutes on air velocities 0.2, 0.4 and 0.8, reported decrease in skin temperature by -1.3˚C, -2.4˚C and -2.6˚C respectively (Daanen 2009). The recovery period was 20 minutes after exposure to SCE.

The mean body temperature decreased in the first 15 minutes, but afterward starts increasing till the end of the exposure to SCE. It has no significant change along the trial period, between 35.1 and 36.1°C. Nevertheless, in some volunteers was recorded a minimal value below 35.0°C (V02-34.60; V05-34.84; V09-34.87; V10-34.86; V12-34.77°C). The lowest mean body temperature in mentioned volunteers were recorded in the middle of the first phase of SCE (10 minutes after entering), before the core temperature started to raise due to higher metabolic heat production. The current literature has described it as the start of the mild form of hypothermia (general freezing) which occurs when the body temperature decrease to 32.0-35.0°C, and appears with shivering, tachycardia, tachypnea and slowness of ideation and compensated dysarthria. On appearing of mentioned clinical features, the workers should start a rewarming process (Mitu and Leon 2011; Golant et al. 2008).

Previous studies conducted in SCE measured core temperature rectally or by tympanum, which are not relevant for the assessments of thermal strain in cold (ISO 9886 2004). In one study measuring rectal Tcore, where the volunteers were sitting at -20˚C for 40 minutes on air velocities 0.2, 0.4 and 0.8, was reported a decrease in core temperature by -0.11˚C, -0.20˚C and -0.23˚C respectively (Daanen 2009). Another study measuring rectal Tcore, where the volunteers were marching 6km/h for 50 minutes at -22.0˚C, reported an increase in core temperature by 0.10˚C (D. C. E. Gavhed and Holmér 1998). As the core temperature in mentioned studies was measured rectally, the explanation might be found in the production of heat from the local muscles, for which is directly affected, depending on the working activity with the legs. By several studies it was concluded that the rectal temperature was highest when the working activity was heavier (T. T. Mäkinen et al. 2001; T. G. Kim et al. 2007; Dragan Brajkovic and Ducharme 2006) and conducting an activity with legs. Another studies conducted 80 to 120 minutes at -24˚C, where the volunteers conducted an order picking activity, reported a decrease in core temperature by -0.90 to -2.20˚C, which might be related to measuring mistakes (ISO 9886 2004).

In this study the intra-abdominal core temperature decreased in the first 10 minutes of exposure to SCE, but afterward increased till the end of exposure to SCE.

It could be explained with higher metabolic heat production (T. T. Mäkinen et al. 2001) and vasoconstriction (Charkoudian 2010). It starts decreasing after exposure to SCE, where volunteers were resting seated at comfort 18.0°C. In this study, the core temperature variations were always less than 1°C difference between the minimum and maximum value, in the most of the cases between 36.5 and 37.5°C.

In this study, both body and core temperatures increased with higher physical exertion even when exposed to SCE and decrease with lower physical exertion even when exposed to comfort temperatures.

More studies should be conducted on the influence of severe cold thermal environment on core and skin temperature variations, taking into account both genders, with more time of exposure to severe cold, conducting different types of activities but with a focus on industrial working activities. Future studies in SCE should be conducted measuring oesophageal and intra-abdominal core temperature (ISO 9886 2004), using more skin temperature measuring points, adding points in the extremities (face, fingers and toes).

6.4 Limitations

The number of volunteers could be higher, although the selection of volunteers was strict and many potential candidates were excluded due to the decision to select only male and non cigarette smokers. It was also challenging to find the volunteers which were willing to attend the trial, especially as still there is some kind of fear on being exposed to severe cold and ingesting the thermometer telemetry capsule.

6.5 Conclusions

Exposure to cold affects health and pose risks for cardiovascular diseases, musculoskeletal complains and symptoms. By increasing of cold sensation increase pain sensation of the body parts where the skin temperature decreased. Validated TSQ questionnaires should be created adding more questions about thermal sensation on specific parts of the body. In the first 20 min of SCE, where in the first 10 minutes was a low physical exertion activity, the mean skin temperature decreased for 1.7°C, but afterward remained stable till the end of exposure to SCE. Tskin recovery period at comfortable room temperature took 20 minutes. The mean body temperature also decreased in the first 15 min of SCE due to low physical exertion activity, but afterward starts increasing till the end of exposure to SCE. In some cases Tbody decreased below 35°C in the first 15 minutes, for which current literature have described as the start of the mild form of hypothermia (general freezing). The core temperature decreased only during low physical exertion activity which is present in the first 10 minutes of exposure to SCE, but afterward increased till the end of exposure to SCE. It was concluded that body and core temperatures increase with higher physical exertion even if exposed to SCE. Therefore, physical exertion is the main parameter to consider when evaluating body and core temperature tendencies.

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7 DISCUSSION AND CONCLUSIONS

Industrial and laboratory researches were conducted according to the systematic review on previous studies in severe cold thermal environment. During the selection of volunteers, bias factors were controlled (as gender, age, weight, height, BMI, body fat, body surface area, medical control, informed consent, consumption of coffee, tea, alcohol, spicy food, medications taking, sleeping hours, type of physical exertion and food consumed prior to participating in the experiments) in order to avoid possible misinterpretations.

The mean skin temperature decreased in both industrial and laboratory researches, which is in accordance to all previous studies observed in the systematic review. In the laboratory research, during the first 20 min of SCE, where in the first 10 minutes was a low physical exertion activity, skin temperature decreased 1.7°C, but then remained stable till the end of exposure. Tskin recovery period at comfortable room temperature took 20 minutes. In one study with same environmental conditions (-20°C, 0.2m/s) (Daanen 2009), with sitting activity, skin temperature decreased for 1.3°C after 40 minutes.

Comparing the articles found through the systematic review, with SCE -20 to -25°C, 7 studies with different types of activities, time of exposure (lighter and heavier), air velocity, measuring rectal and tympanum temperature, found the core temperature to decrease throughout the exposed period (Wiggen et al. 2011; Ozaki, Nagai, and Tochihara 2001; Oksa et al. 2004; Kluth, Penzkofer, and Strasser 2013; Kluth, Baldus, and Strasser 2012; T. G. Kim et al. 2007; Daanen 2009). Only one study with mentioned air temperature limits, conducting a walking activity and measuring rectal temperature found the core temperature to increase (D. C. E. Gavhed and Holmér 1998).

The industrial study from this thesis in some cases showed a decrease of core temperature when exposed to SCE, but also when not exposed to SCE. By laboratory studies, it was confirmed that lower physical activity (which was in the first 10 minutes of exposure to SCE) result with decreasing in core temperature. Nevertheless, by both industrial and laboratory research, it was confirmed a general tendency of increase in core temperature during work in SCE, which was concluded to be related with vasoconstriction and higher heat production as a result from higher physical exertion.

The hypothesis 1, 2 and 3, regarding core temperature variations for properly dressed healthy male subjects using cold protective equipment were found to be:

- *Hypothesis 1: "The core temperature decreases when workers are exposed to severe cold thermal environment (-20°C or below)."*

  - True for Lower physical exertion

  - False for Higher physical exertion

- *Hypothesis 2: "The core temperature of active workers will decrease below 36.0°C after 50 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False for Higher physical exertion

- *Hypothesis 3: "The core temperature of active workers will decrease below 36.0°C after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False for Higher physical exertion

The hypothesis 4 and 5, regarding core temperature recovery at comfortable room temperature ±18°C for seated (low physical exertion activity) healthy male subjects were found to be:

- *Hypothesis 4: "The core temperature will recover only in 10 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False (The core temperature didn't need to recover after SCE exposure)

- *Hypothesis 5: "The core temperature will recover only in 60 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False (The core temperature didn't need to recover after SCE exposure)

The hypothesis 6, 7 and 8, regarding skin temperature variations for properly dressed healthy male subjects using cold protective equipment were found to be:

- *Hypothesis 6: "The skin temperature decreases when workers are exposed to severe cold thermal environment (-20°C or below)."*

  - True for Lower physical exertion

  - True for Higher physical exertion

- *Hypothesis 7: "The skin temperature of measured points in the extremities will decrease to 15.0°C after 50 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False for Higher physical exertion (In industrial and laboratory trials conducted in this research measured skin temperature in the left hand, left calf and forehead, further studies should be conducted measuring fingers and toes).

- *Hypothesis 8: "The skin temperature of measured points in the extremities will decrease to 15.0°C after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False for Higher physical exertion (In industrial and laboratory trials conducted in this research measured skin temperature in the left hand, left calf and forehead, further studies should be conducted measuring fingers and toes).

The hypothesis 9 and 10, regarding skin temperature recovery at comfortable room temperature ±18°C for seated (low physical exertion activity) healthy male subjects were found to be:

- *Hypothesis 9: "The skin temperatures of all measured points will recover only in 10 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False (The skin temperature recovery period was 20 minutes)

- *Hypothesis 10: "The skin temperature of all measured points will recover only in 60 minutes after 60 minutes of exposure to severe cold thermal environment (-20°C or below)."*

  - False (The skin temperature recovery period was 20 minutes)

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8 FUTURE RESEARCH

There is a need to improve present guidelines from national safety agencies, adding work/rest period recommendations for working in severe cold environments with air temperatures higher than -26.0˚C (between -20 and -25.0˚C, which is commonly used temperature in the frozen food industry).

The countries and ISO should develop recommendations for exposure to cold which are easy to implement by the organizations. Further studies should be conducted in severe cold thermal environment with different air velocities, time of exposure, different types of activities and physical exertion, contributing to the optimization of the work/rest period in order to confirm or deny the values given by standards. More experiments should be conducted in order to confirm or deny the values defined in the standards. Experiments should be conducted in real industrial environments in order to understand better the nature of working in frozen food industries.

Studies should be conducted with carefully specified volunteer physical characteristics with all previously mentioned (if possible) bias factors, with a bigger sample, including both genders and differently aged subjects, acclimatized and non-acclimatized subjects.

Core temperature should be measured through oesophageal or intra-abdominal temperature, while skin temperature should have more measuring points (adding points in the extremities as face, fingers and toes).

There is a need to improve the ISO 9886:2004. According to ISO 9886:2004, Annex A, table A.2, oesophageal and intra-abdominal temperature are the only relevant for the assessment of thermal strain in cold climatic conditions. This is in contradiction with ISO 9886:2004, Annex C, chapter C.2.2, where the only relevant for the assessment of thermal strain in cold climatic conditions apart from oesophageal and intra-abdominal temperature was included the rectal temperature.

There is a need to create validated questionnaires for assessment of health, thermal sensation and pain for those exposed to severe cold thermal environment. Questionnaires could find bases in the CWHQ (Annex D of the ISO 15743:2008(ISO 15743 2008)) and TSQ (Annex B of the ISO 10551:199(ISO 10551 1993)), but also adding questions for specific parts of the body.

References

ISO 10551. 1993. "Ergonomics of the Thermal Environment – Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales." *International Standards Organisation*.

ISO 15743. 2008. "Strategy for Risk Assessment, Management and Working Practice in Cold Environment." *International Standards Organisation*.

APPENDIX

Appendix 1 – Project Proposal (Ethics Committee)

Ethical Committee of the University of Porto (EC UP)
Praça Gomes Teixeira, 4099-002 Porto, Portugal
Attn: Prof. Jose A. R. Duarte
Attn: Mrs. Ana Miguel, Ph.D.
Attn: Members of the Ethical Committee of the University of Porto

Porto, July 12, 2015

Subject: Ethical Committee Research Project Evaluation

Dear Prof. Jose Duarte, Mrs. Ana Miguel, and other members of the Ethical Committee of the University of Porto,

I am using this letter in order to introduce you to my research project abstract on the theme *"Influence of Severe Cold Thermal Environment on Task Performance"*.

Investigators:

1. Associate Professor João Manuel Abreu dos Santos Baptista, Ph.D.
   Faculty of Engineering, University of Porto; *(CV enclosed as document 1)*
2. Associate Professor Mário Augusto Pires Vaz, Ph.D.
   Faculty of Engineering, University of Porto;
3. Assistant Professor José Castela Torres Costa, Ph.D.
   Faculty of Medicine, University of Porto; *(CV enclosed as document 2)*
4. Doctoral Student Tomi Zlatar
   Doctoral Program on Occupational Safety and Health (DemSSO); *(CV enclosed as document 3)*

Main experiments should be conducted in a SONAE frozen food facilities located in Lisbon and Porto and in a controlled environment, at the Research Laboratory on Prevention of Occupational and Environmental Risks (PROA/LABIOMEP), Faculty of Engineering, University of Porto.

RESEARCH PROJECT ABSTRACT: Exposure to cold is a significant risk factor in indoor industrial activities (e.g. food industry). Cold affects humans by lowering body performance and raising fatigue, health problems and safety risks, in particular injuries and accident risks. During the summer, outdoor air temperatures in Portugal are normally higher compared with the indoor temperatures used in a food processing industry, which influence the human body response. The aim of this project proposal is to further previous research on the influence of cold thermal environment on human fatigue and performance, in order to reach usable information to improve working conditions, minimize musculoskeletal disorders and work absenteeism. The results obtained in the SONAE frozen food industry will be compared with the results obtained during laboratory experiments conducted in FEUP climatic chamber. Various techniques and equipment will be used in order to measure indoor and outdoor air temperature, relative humidity, skin body temperature, maximal voluntary contraction, the thermal sensation and the "Cold work health questionnaire". The experiment should be conducted in an industry where workers are usually exposed to cold environment temperatures, for each subject to be tested for 3-5 consecutive days, doing the same task during the same period. All subjects should wear clothes with same clothing insulation factor. Afterward, the experiment should take place in comfort environment temperatures, with same subjects or subjects with similar physical characteristics, conducting a similar type of movement and exertion, during same period as the primary group. In order to get a wide variety of comparable results, a significant sample with different physical *characteristics should be evaluated (age, gender, height and weight). Prior to conducting experiments, all subjects should answer the "Participation" and "Trial" forms (enclosed as document 7) in order to avoid bias factors. Experiments will be based on the literature review presented in the article "Physical working performance in cold thermal environment: a short review". Further systematic review will be conducted during the mobility period outside of Portugal. All results will be presented in the doctoral thesis, in scientific articles and conferences. This work will increase the knowledge in this field and can benefit directly worldwide, all sectors of the economy working in conditions of thermal stress by cold, contributing to the general community wellbeing.*

A) Influence of cold thermal environment

Exposure to cold environment is a significant risk factor in industrial activities, present in out-door during the winter season and indoor present in all seasons (Tochihara, 2005). Indoor expo-sure in mostly related to working activities in the fresh food industry with temperatures from 0-10ºC and frozen goods at temperatures below -20ºC, while cold exposure in outdoor activities is present in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work and related occupations (Mäkinen et al., 2006).

When the human body is exposed to cold, the initial response is to preserve heat by reducing heat loss. The skin blood flow, especially in extremities is reduced by vasoconstriction (Charkoudian, 2010), which leads to increased systolic and diastolic blood pressure, lowered heart rate and body temperature in extremities (Gavhed, 2003). It is very well documented that there is an increase mortality related to acute myocardial infarction (AMI) during the cold season (Chang, Shipley, Marmot, & Poulter, 2004; Gómez-Acebo, Llorca, & Dierssen, 2013; Kriszbacher, Bódis, Csoboth, & Boncz, 2009; Sheth, Nair, Muller, & Yusuf, 1999; Spencer, Goldberg, Becker, & Gore, 1998; Turin et al., 2011). Some authors considered fluctuation in air temperatures as a major influence on AMI and stroke, especially when it comes to sudden decrease in temperature in a 24-hour period (Gill et al., 2013). A 5ºC reduction in mean air temperature was associated with 7 and 12% increase in the expected hospitalization rates of stroke and AMI, respectively (Chang et al., 2004). On other hand, Kriszbacher suggested that beside temperature fluctuations, the barometric pressure and front movements greatly contributed to AMI cases (Kriszbacher et al., 2009). Nevertheless, cardiovascular diseases can be reduced by good management program of risk factors at work (Mitu & Leon, 2011).

Dehydration was documented as another significant challenge in humans extendedly exposure to cold, as it reduces work capacity, appetite, alertness, and can lead to other medical problems such as constipation, kidney disorders and urinary infections (Young et al., 1992).

Further on, it was found that repetitive work in the cold, at the ambient temperature of 4 °C, increased upper extremity muscular strain compared to similar work at 19 °C (Sormunen, Ritamaki, et al., 2009). Health problems arising from repetitive movements were recorded in various specific upper limb disorders as it is carpal tunnel syndrome (narrowing around the middle wrist nerve), lateral epicondylitis (inflammation or irritation of the attachment of ligaments to the outer elbow joint) and wrist tendinosis (degeneration of the tendon in the wrist) (Council, 2013).

Finger temperature was found to be an important indicator of hand and finger dexterity (Wiggen, Heen, Færevik, & Reinertsen, 2011). Manual dexterity was severely impaired when hand skin temperature decreased below 20ºC (Gavhed, 2003) or finger skin temperature decreased below 14°C (Daanen, 2009). It was found that shivering directly affected finger dexterity performance due to the involuntary muscle movements that affected hand/finger steadiness (Brajkovic & Ducharme, 2001). Reduced manual dexterity influenced in decreasing work efficiency and productivity, and increasing the risk of accidents (Kim, Tochihara, Fujita, & Hashiguchi, 2007).

During acute cold exposure, cognitive functions such as working memory, reaction time, executive function and choice reaction time were reduced, and stayed reduced for 60 min after removal from the cold, which influenced working performance (Muller et al., 2012) and which increased the risk of accidents.

Decreasing of the body temperature resulted in increasing the muscular strain which led to musculoskeletal disorders (Juha Oksa, Ducharme, & Rintamäki, 2002), cooling of the tissues led to discomfort, deterioration of performance, work accidents (Mäkinen & Hassi, 2009) and increased likelihood of reporting low back symptoms (Dovrat & Katz-Leurer, 2007).

Throughout the systematic review, 37 articles were found to have conducted experiments on air temperatures lower than -5°C. Only 6 of those articles considered a simulation of a real working task from a frozen food industry. It was noticed that all of the articles partially consider bias factors as considering non-smokers, 12hours abstain from alcohol drinking, coffee and tea consuming, what the volunteers were eating, illness history, medical control and medicine taking, physical exertion 12hours prior to the test, sleeping hours of the volunteer and non-eating or drinking anything at least 2h before the participation to the experiment. Further on, it was found that previous experiments considered partially equipment as blood pressure, heart rate, maximal voluntary contraction, skin and core body temperature, oxygen consumption and thermal sensation.

B) Research project objectives

The main objective of this research project is to study the influence of the resting period between cold exposures on task performance.

The secondary objectives of this research project are:

1. Observe the effects of cold thermal environment on force output (maximal voluntary contraction)
2. Observe the effects of cold thermal environment on human dexterity
3. Observe the effects of cold thermal environment on skin and core body temperature
4. Observe the effects of cold thermal environment on human metabolism
5. Observe the effects of cold thermal environment on heart rate and blood pressure

C) Research project phases

This research project will be conducted in several phases:

1. Systematic review – literature review
2. Experiments in a controlled environment at the Research Laboratory on Prevention of Occupational and Environmental Risks (PROA/LABIOMEP), Faculty of Engineering, University of Porto, Portugal
3. Experiments in a real frozen-food processing environment, SONAE facilities, Porto, Portugal
4. Data analysis, interpretation and discussion of the results

D) Volunteers, thermal environment and equipment

All volunteers should read and sign the informed consent previous to participating to the experiments (enclosed as document 4 in English language and document 5 in Portuguese language).

<u>*2nd Phase – laboratory experiments (PROA/LABIOMEP)*</u>

<u>Volunteers -</u> The number of subjects might vary due to the number of volunteers which would like to participate. An approximation is that there will be from 10 to 20 male volunteers. Subjects will be students or other young males aged from 18 to 38. Medical control should be conducted on all volunteers in order to select volunteers which are healthy or/and don't have medical contraindication to the experiment (namely heart disease, vascular disease, respiratory disease, intolerance to cold, cold urticaria, other forms of urticaria or angioedema, musculoskeletal alteration). Height and weight should be measured. The volunteers should be non-cigarette smokers or occasional smokers (less than 10 cigarettes per day), but if occasional smokers, than should avoid cigarette smoking for at least 12h before the test; not drink coffee, tea or alcohol for at least 12h before the test; not eat spicy food at least 12h before the test; not eat or drink anything 2h before the test (only some water on body temperature if needed); not taking any medication at least 12h before the test; sleep normally before the test (usually about 8h); not conducted greater physical exertion than it is usual for the volunteer at least 1day before the test.

<u>Thermal environment –</u> Subjects will be exposed during 3 phases of 20 min to the air temperature about -20±2°C (severe cold temperature). The resting period between exposures will be 10 minutes and it will be on room temperature (from 20 to 28ºC). The trials will be aborted if: the subject feel any symptoms such as dizziness, nausea and general malaise; the core body temperature, measured by the sensor go lower than 36ºC (ISO 9886); the local skin temperature (in particular for the extremities: face, fingers and toes) gets to 15ºC (ISO 9886). Afterward, the

trials will be repeated in the same way except the air temperature will be comfortable (~22°C air temperature and ~60% relative humidity) instead of severe cold. Time between two exposures should be at least 2 days and the first exposure should be always on comfortable temperatures.

Equipment – For this phase of the research project, there will be used non-intrusive equipment for measuring force output (maximal voluntary contraction), the thermographic camera, skin temperature sensors, heart rate, if possible equipment for measuring oxygen consumption and metabolism and the "Cold work health questionnaire", and intrusive equipment – ingestible pill sensor for measuring core body temperature. When exposed to severe cold, volunteers will wear special cold protective equipment (jacket with a hood, trousers, boots and gloves above their normal clothing (socks, underpants, t-shirt, trousers, thinly long-sleeved shirt). When exposed to comfort they will be wearing: sneakers, socks, underpants, t-shirt, shots).

The most important device is the climatic chamber - fitoclima 25000EC20 - built according the rules and directives of the European Commission, regarding the requirements of health and safety. This climatic chamber has the ability to simulate exposure to different thermal environment conditions with air temperature from -20ºC to + 50ºC and relative humidity from 30% to 98%. The camera is also equipped with CO_2 and O_2 sensors.

Type of movement – Putting three boxes (each weighting 5 kg), one by one, from the first table (ergonomically adapted height) on their left, to the second table on their right (always in the same way and order, doing the same type of movement in the similar velocity. After putting all of the boxes from the left to right side, the subject walk to the other side and turn, facing the table two (now with all the boxes) on it's left, and the table one on his right. He repeats the same task putting the boxes from the left to the right table conducting the same type of repetitive movement during each 20 min of exposure.

3rd Phase – industrial experiments (SONAE)

Volunteers - The number of subjects might vary due to the number of volunteers which would like to participate. An approximation is that there will be about 15 male workers. Subjects will be workers from the frozen food processing industry, usually exposed to these air temperatures, aged depending on the willing to volunteer for this research project. Height and weight should be measured. The volunteers should be non-cigarette smokers or occasional smokers (less than 10 cigarettes per day), but if occasional smokers, than should avoid cigarette smoking for at least 12h before the test; not drink coffee, tea or alcohol for at least 12h before the test; not eat spicy food at least 12h before the test; not eat or drink anything 2h before the test (only some water on body temperature if needed); not taking any medication at least 12h before the test; sleep normally before the test (usually about 8h); not conducted greater physical exertion than it is usual for the volunteer at least 1day before the test.

Thermal environment – Subjects will be exposed for 2 to 4 days (each) to air temperature -22±2°C (severe cold temperature) during their working period (as usually). Afterward, subjects will be exposed for 1 day (each) to normal environmental working conditions outside the refrigerator. The SONAE management will be responsible if the workers continue working after: the subject feels any symptoms such as dizziness, nausea and general malaise; the core body temperature, measured by the sensor goes lower than 36ºC (ISO 9886); the local skin temperature (in particular for the extremities: face, fingers and toes) gets to 15ºC (ISO 9886).

Equipment – For this phase of the research project, there will be used non-intrusive equipment for measuring force output (maximal voluntary contraction), finger/hand dexterity, the thermographic camera, skin temperature sensors, heart rate, if possible equipment for measuring oxygen consumption and metabolism and the "Cold work health questionnaire", and intrusive equipment – ingestible pill sensor for measuring core body temperature. Workers will wear same clothes as they usually do while working in the SONAE frozen food industry. The workers of SONAE frozen food industry will be working in the usual refrigerator.

Type of movement – The movements which they usually conduct during their working activities.

Ingestible pill sensors for measuring core body temperature

The core body temperature is one of the most important parameters to monitor as it is one of the best methods to reduce health and safety risks while being exposed to cold temperatures. As well, it is essential when studying the influence of cold thermal environment on human fatigue and performance. It has been applied in different studies, in laboratories or in real conditions, in particular: athletes, students and military. Ingestible thermal sensors (STI) allowed measurements of core body temperature, and was applied by researchers in several studies, validated by different authors and approved by ethics committees of their respective organizations. These ingestible pill sensors were already approved by the Ethical Committee of the University of Porto for the project named "Influência do Ambiente Térmico na resposta cognitiva em Atividades Sedentárias", approval number: 04/CEUP/2012. Ingestible pill sensor for measuring core body temperature (thermometer telemetry capsule) should be swallowed with water for at least 5 hours before each test; travels along the digestive tract harmlessly, leaving naturally within 24 to 72 hours. The sensors begin to transmit one minute after the activation has been made by the external monitor, sending detail every 15 seconds to a monitor designated *EQ02 Life Monitor - Electronics Sensor Module (SEM) which transmits the data via Bluetooth (enclosed as document 6)*. The details will be sent to the telemetry recording system with an accuracy of +/- 0.01°C. The Ingestible Core Temperature Capsule has dimension of 8.7mm diameter by 23mm length.

2nd Phase – laboratory experiments (PROA/LABIOMEP)

GENERAL EXPERIMENTAL DESING (Protocol)

Enclosed as a separated document with a title: *EC (document 8) – Detailed Protocol – FEUP's laboratory*

3rd Phase – industrial experiments (SONAE)

GENERAL EXPERIMENTAL DESING (Protocol)

Before the experimental day	**General subject information (name, date of birth…) Menstrual cycle and expected time for the first phase Illness history, medicine taking, cigarette smoking Explain the experimental protocol and the research value Instructing subjects not to drink coffee, tea, alcohol and eat spice food at least 12 hours before Schedule the experimental day**
Day before the experimental day	**Remind subjects for the experiment and to take the core body pill Remind subjects not to drink coffee, tea, alcohol and eat spice food at least 12 hours before Verify if the subject is in the first phase of the menstrual cycle**
Experimental day Before exposed to cold	**Height and weight measurements Get the volunteer to read and sign the informed consent General questionnaire on food, drinks consumption, sleeping hours and physical exertion putting skin temperature sensors, heart rate sensor checking core temperature pill Get volunteers to dress up with specific clothes and shoes in order to have all subjects wearing clothes with same clothing insulation factor (Clo) MVC test before finger dexterity test thermography recording**
Experiment while exposure to cold 1st part	**Measuring skin and core body temperature, heart rate**
Pause for lunch	**MVC test after Thermography recording Finger dexterity test Measuring the weight of the worker**
	Control what they eat/drink
	Checking the sensors for skin and core body temperature, heart rate sensor MVC test before Thermography recording Finger dexterity test Measuring the weight of the worker
Experiment while exposure to cold 2nd part	**Measuring skin and core body temperature, heart rate**
Experimental day After being exposed to cold	**MVC test after thermography recording finger dexterity test Cold work health questionnaire Measuring weight of the workers**

Interaction between the researcher and SONAE:

The researcher should be passive, only measuring, assessing the described parameters, and not interfering with the working conditions. At the end of the experiment, the researcher may give to the company some data from the conducted measurements.

There are multiple benefits as an outcome from these experiments: lower fatigue, lower health and safety risks, musculoskeletal disorders, injuries and accidents among workers, higher working performance and productivity, lower direct costs (worker's compensation payments, medical expenses, and costs for legal services) and lower indirect costs (training replacement employees, accident investigation and implementation of corrective measures, lost productivity, repairs of damaged equipment and property, and costs associated with lower employee morale and absenteeism), raising the knowledge and understanding on the influence of cold thermal environment on humans while conducting working activities.

Sincerely,

Tomi Zlatar

In the annex, 8 documents are enclosed:

1. *EC (document 1)_CV_prof. Baptista_2014*
2. *EC (document 2)_CV_prof. Torres Costa_2013*
3. *EC (document 3)_CV_Zlatar_2015*
4. *EC (document 4) - Informed consent*
5. *EC (document 5) - Consentimento informado*
6. *EC (document 6) - Core body temperature sensor - EQ02 Life Monitor - Electronics Sensor Module (SEM)*
7. *EC (document 7) – Participation and Trial forms*
8. *EC (document 8) – Detailed Protocol – FEUP’s laboratory*

Appendix 2 – Detailed protocol (Ethics Committee)

DETAILED PROTOCOL

FEUP's LABORATORY
Title: Influence of Cold Thermal Environment

There are several phases of this detailed protocol:

- **A) Two weeks before the experimental day**
- **B) Medical control day**
- **C) One day before the experimental day**
- **D) On experimental day**
    - 1) Before the volunteer arrives
    - 2) When the volunteer arrives
        - *2.1. Before exposed to cold*
        - *2.2. While exposed to cold*
        - *2.3. After exposed to cold*
        - *2.4. Pause*
        - *2.5. Before exposed to comfort*
        - *2.6. While exposed to comfort*
        - *2.7. After exposed to comfort*
    - 3) After the experiment is finished

A) Two weeks before the experimental day:

1.	Contact possible volunteers and shortly explain the experimental protocol
2.	Get information on if they are cigarette smokers or not
3.	Schedule the medical control
4.	Give the instruction flyer to the volunteers (with short explanation on the purpose, benefits, equipment to be used, with instructions on which kind of food or drinks and other not to use prior to the experimental day)
5.	Schedule the experimental days

B) Medical control day:

1.	Meet with the volunteer and go to conduct the medical control
2.	Get the volunteer to read and sign the informed consent (only the first time the voluntary attend this type of experiment)

C) One day before the experimental day:

1.	Meet with the volunteer scheduled for the next day experiment
2.	Verify if there are no changes in health or other volunteer's issues
3.	Give the core body temperature pill to the volunteer and explain how and when to take the pill, tell the volunteer not to open the package with the pill before they take it
4.	Remind the volunteer not to drink coffee, tea, alcohol and not to eat spicy food from today until the experimental trial finish

D) On experimental day:

1) Before the volunteer arrives:

1.	Be at least 1 hour before the volunteer in the laboratory	
2.	Note the air temperature and relative humidity	
	- Outside the refrigerator air temperature	
	- Outside the refrigerator relative humidity	
	- Inside the refrigerator air temperature	
	- Inside the refrigerator relative humidity	
3.	Turn on the computer and all the programs needed for the experiment:	
	- EQ02 Life Monitor (core body temperature)	
	- (skin body temperature)	
	- ThermaCAM Researcher Professional 2.10 (thermography camera)	
4.	Check all the equipment:	
	- Skin temperature sensors (Sensors tempPlux - 7)	
	- Skin temperature sensors (Monitor BioPlux)	
	- Heart rate sensor (K4)	
	- Alcohol bottle (for cleaning)	
	- Patch of cotton (for cleaning)	
	- Disposable gloves	
	- Adhesive tape (for sensors)	
	- Towel for cleaning	
	- Core body temperature pill (to give at the end for the experiment of tomorrow)	
	- Gear shift (Ativador Equivital, Hidalgo)	
	- Belt (Colete Equivital) – adequate size for the volunteer	
	- Device for core temperature (LifeMonitor, Equivital)	
	- Scissors	
	- MVC	
	- Blood pressure equipment	
	- Cold protective clothes	
	- Check the weighting scale	
	- Boxes and tables	
	- **ADAPT THE TABLES HEIGHT TO THE VOLUNTEER (20 cm from the elbow)**	
5.	Check all printed materials:	
	- Participation and Trials form	
	- Thermal sensation test	
	- Cold work health questionnaire	
	- All the protocols	

2) When the volunteer arrives:

1st phase

1.	Meet the volunteer in front of the FEUP's entrance								
2.	Check if the core temperature pill is functioning								
3.	Question the volunteer and fulfill the Participation and trials form								
4.	Explain to the volunteer the task (putting the boxes from one table to another, always using the hands in the same way and doing 3 boxes each 15 seconds, not faster or slower)								
5.	Measure and register the height of the volunteer. The volunteer should climb the scale platform, with the back facing the researcher. The volunteers back, head, buttocks, legs and heels should be touching the ruler of height scale. (only the first time the voluntary attend this type of experiment)								
	HEIGHT = cm								
6.	Measure and register the weight of the volunteer. The volunteer should wear underwear, afterward to climb the scale platform by facing the weight scale and the researcher								
	WEIGHT = kg								
7.	Explain to the volunteer that if he feel dizziness or not feeling good, the experiment can be stopped								
8.	Put 8 skin temperature sensors according to ISO 9886 (tape better the leg and the arm)								
9.	Put the K4 heart rate belt								
10.	Put the core belt								
11.	Put the t-shirt								
12.	MVC test	1.		15 sec	2.		15 sec	3.	
13.	Blood pressure measurement	SYS			DYS		HR =		
14.	Help the volunteer to dress the comfort OR cold protective clothes and shoes being careful not to flexion the wires of the skin and heart sensors								
15.	Thermal sensation questionnaire								
16.	Inform the volunteer to count the number of boxes he put from one side to the other								
17.	Assure that a period of 20 minutes passed from the volunteer's arrival								
18.	Let the volunteer enter the climatic chamber								
19.	Put mark on K4 results								

2nd phase

1.	Note the time the volunteer entered the climatic chamber
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;
2.	Thermal sensation questionnaire
3.	Start conducting the task
4.	Control measuring parameters and abort the experiment if: - the subject feel any symptoms such as dizziness, nausea and general malaise - the core temperature go lower than 36.0ºC (ISO 9886) - the local skin temperature go lower than 15.0ºC (ISO 9886) (in particular for the extremities: face, fingers and toes)
5.	Thermal sensation questionnaire
6.	Let the volunteer exit the climatic chamber
7.	Put mark on K4 results

3rd phase

1.	Note the time the volunteer exit the climatic chamber								
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;								
2.	Write down the number of boxes he put from one side to the other								
3.	Thermal sensation questionnaire								
4.	MVC test	1.		15 sec	2.		15 sec	3.	
5.	Blood pressure measurement	SYS			DYS		HR =		
6.	Thermal sensation questionnaire								
7.	Remind the volunteer to count the number of boxes he put from one side to the other								
8.	Let the volunteer enter the climatic chamber								
9.	Put mark on K4 results								

4th phase

1.	Note the time the volunteer entered the climatic chamber
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;
2.	Thermal sensation questionnaire
3.	Start conducting the task

4.	Control measuring parameters and abort the experiment if: - the subject feel any symptoms such as dizziness, nausea and general malaise - the core temperature go lower than 36.0ºC (ISO 9886) - the local skin temperature go lower than 15.0ºC (ISO 9886) (in particular for the extremities: face, fingers and toes)
5.	Thermal sensation questionnaire
6.	Let the volunteer exit the climatic chamber
7.	Put mark on K4 results

5th phase

1.	Note the time the volunteer exit the climatic chamber								
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;								
2.	Write down the number of boxes he put from one side to the other								
3.	Thermal sensation questionnaire								
4.	MVC test	1.		15 sec	2.		15 sec	3.	
5.	Blood pressure measurement	SYS			DYS		HR =		
6.	Thermal sensation questionnaire								
7.	Remind the volunteer to count the number of boxes he put from one side to the other								
8.	Let the volunteer enter the climatic chamber								
9.	Put mark on K4 results								

6th phase

1.	Note the time the volunteer entered the climatic chamber
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;
2.	Thermal sensation questionnaire
3.	Start conducting the task
4.	Control measuring parameters and abort the experiment if: - the subject feel any symptoms such as dizziness, nausea and general malaise - the core temperature go lower than 36.0ºC (ISO 9886) - the local skin temperature go lower than 15.0ºC (ISO 9886) (in particular for the extremities: face, fingers and toes)
5.	Thermal sensation questionnaire
6.	Let the volunteer exit the climatic chamber
7.	Put mark on K4 results

7th phase

1.	Note the time the volunteer exit the climatic chamber								
	TIME: _____ ; CORE TEMP: _____ ; HR: _____ ; O2: _____ ; CO2: _____ CH TEMP: _____ ; CH HR: _____ ; ROOM TEMP: _____ ; ROOM HR: _____ ;								
2.	Write down the number of boxes he put from one side to the other								
3.	Thermal sensation questionnaire								
4.	MVC test	1.		15 sec	2.		15 sec	3.	
5.	Blood pressure measurement	SYS			DYS		HR =		
6.	Save data k4								
7.	Save data skin plux								
8.	Save data core pills								
9.	Save data camera recording								
10.	Remove the k4								
11.	Remove the t-shirt, belt core, belt k4, sensors								
12.	The volunteer can take a shower / **NOT DRINK WATER!**								
13.	Measure and register the weight of the volunteer. The volunteer should wear underwear, afterward to climb the scale platform by facing the weight scale and the researcher								
	WEIGHT = kg								
14.	Cold work health questionnaire / **JUST FOR COLD EXPERIMENT**								
15.	Subjectively assessed age-related stress and strain associated with working in the cold questionnaire / **JUST FOR COLD EXPERIMENT**								
16.	Thank the volunteer for the contribution								
17.	Give to the volunteer another core body temperature pill for the next day and remind the volunteer not to drink coffee, tea or alcohol, and not to eat spicy food								

C3) After the experiment is finished:

1.	Check if the data were stored according to the following checklist:	
	1. Core temperature records	
	2. Skin temperature	
	3. K4 records	
	4. Blood pressure	
	5. MVC records	
	6. Anthropometric data	
	7. Thermal sensation questionnaire	
	8. Cold work health questionnaire and Subjectively assessed strain questionnaire	
2.	Put all data in the same folder at the UP account and on the USB stick	
3.	Clean all the equipment with alcohol and put all equipment at its place	
4.	Put to charge plux and k4	

COMFORT		22°C & 60%		22°C & 60%		22°C & 60%	
	Room	Climatic chamber	Room	Climatic chamber	Room	Climatic chamber	Room
	20’	20’	10’	20’	10’	20’	20’
	TOTAL = 2 hours						
	1	**2**	**3**	**4**	**5**	**6**	**7**

SEVERE COLD		-20°C		-20°C		-20°C	
	Room	Climatic chamber	Room	Climatic chamber	Room	Climatic chamber	Room
	20’	20’	10’	20’	10’	20’	20’
	TOTAL = 2 hours						
		Or if core temp. decrease to 36.5°C	Or till core temp. increase to 37.0°C	Or if core temp. decrease to 36.5°C	Or till core temp. increase to 37.0°C	Or if core temp. decrease to 36.5°C	
	1	**2**	**3**	**4**	**5**	**6**	**7**

Appendix 3 – Ethics Committee Approval

U.PORTO

COMISSÃO DE ÉTICA

PARECER N.º 06/CEUP/2015

OPINION OF THE ETHICS COMMISSION OF UNIVERSIDADE DO PORTO ON THE FOLLOWING PROJECT:

"Influence of Severe Cold Thermal Environment on Task Performance"

SUBMITTED BY:

Tomi Zlatar, PhD student

SUPERVISED BY:

João Manuel Abreu dos Santos Baptista, PhD,

Mário Augusto Pires Vaz, PhD,

José Castela Torres Costa, MD, PhD

INSTITUTION WHERE THE PROJECT WILL BE CONDUCTED:

Facilities of SONAE company in Porto, and PROA/LABIOMEP at FEUP.

U.PORTO

COMISSÃO DE ÉTICA

The project entitled "*Influence of Severe Cold Thermal Environment on Task Performance*" aims to analyze the influence of severe cold environment exposition (-20 ± 2° C) in (i) some physiological parameters (core and skin temperature, heart rate, blood pressure, oxygen consumption), (ii) well-being (assessed by a questionnaire), and (iii) physical fitness (assessed by maximal muscular strength and movement accuracy), of students not familiarized with these extreme conditions and of workers who make their routine work in these extreme environments. To achieve these purposes the project will be developed into two phases, initially using a sample of 10 - 20 students (ages between 18 and 38 years) and in a second phase, using 15 SONAE employees that work routinely in cold storage for frozen food handling.

Considering the risks/benefits to participate in the study, apparently there are no benefits or advantages for all the subjects. Regarding the students, their inherent risk to extreme temperatures exposition is attenuated by a prior medical examination, with exclusion of those more susceptible, as well as by the continuous monitoring of physiologic variables during the exposure. Regarding the SONAE employees and considering the potential conflict between the company interests and the research's outcomes, the author ensures that his attitude in the company will be of total passivity, only assessing the employees without interfering with their daily tasks or rules within the enterprise. Although not mentioned in the text, it may exist some social relevance of the study if in the future the company SONAE will take into account the obtained results, adjusting the workers' time of exposure to cold environments according to their physiological limitations.

In the information sheet and in the statement of informed consent the risks to participate in the experiment are clear stated and it is also guaranteed that the obtained results will be treated anonymously. It is also guaranteed the possibility of the participant to quit the study whenever he wants, without any justification. The supervisors of the project show competence to lead it successfully.

Considering these characteristics, as well as the competence of the research team, the Ethics Committee of the University of Porto (CEUP) does not foresee ethical limitations and has no objections to the realization of this project.

Porto, 23rd July 2015

The reporter
Prof. Doutor J A Ramos Duarte

President of CEUP
Prof. Doutor M Pestana

Appendix 4 – List of original papers

The thesis is based on following 4 published/accepted papers and 4 submitted but yet unpublished papers on the Systematic review, Industrial Research, Laboratory Research and the evaluation of legislations and standards in SCE. Published/accepted papers are presented in the further pages of this section:

1. Zlatar T, Baptista J, Costa J. Physical working performance in cold thermal environment: A short review. In: *Occupational Safety and Hygiene III*. CRC Press; 2015:401-404. doi:10.1201/b18042-81.
2. Zlatar T, Vardasca R, Marques AT. Changes in face and hands skin temperatures during exposure to moderate cold thermal environment. In: *Occupational Safety and Hygiene III*. CRC Press; 2015:267-271. doi:10.1201/b18042-55.
3. Zlatar T. Cognitive Working Performance in Moderate Cold Thermal Environment: a systematic review. *UPorto J Eng*. 2015;1(1):114-121. http://www.open-jim.org/index.php/upjeng/article/viewFile/128/115.
4. Zlatar T, Barkokebas B, Martins L, et al. Influence of Cold Thermal Environment on Packing Workers from the Frozen Food Processing Industry. In: *Occupational Safety and Hygiene V*. ; 2017:Accepted, waiting for publishing.

Appendix 5 – Paper 1

Occupational Safety and Hygiene III – Arezes et al. (Eds)
© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02765-7

Physical working performance in cold thermal environment: A short review

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ABSTRACT: Exposure to cold thermal environment is a significant risk factor in industrial activities, influencing the human physical performance. The aim of this work is to contribute with a short review on physical working performance of humans exposed to cold thermal environment, by classifying different studies conducted in that area. Using appropriated keywords and expressions, a short review of English articles has been done, by searching electronic databases. Only articles related to worker's physical performance while exposed to cold thermal environment were included. Ten experimental articles were included. The number of participants varied from 6 to 30 workers. The findings of this short review indicate that moderate and severe cold environment in general reduces physical performances. However the amount, level and quality should be enlarged, considering different tasks, both genders and exposure to different cold conditions.

1 INTRODUCTION

Exposure to cold environment is a significant risk factor in industrial activities, present in outdoor during the winter season and indoor present in all seasons (Tochihara, 2005). Indoor exposure in mostly related to working activities in the fresh food industry with temperatures from 0–10ºC and frozen goods at temperatures below –20ºC, while cold exposure in outdoor activities is present in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work and related occupations (Mäkinen et al., 2006).

Outdoor exposure to cold is of particular interest for regions in high latitude environments where winter seasons last for several months (for example Finland with winter lasting for 3–7 months (Mäkinen, 2007)). The degree of exposure to cold is dependent on several factors such as occupation, gender, age, health, exercise activity, and education (Mäkinen, 2007). Exposure to cold thermal environment, increased muscular strain, different musculoskeletal complains and symptoms are common (Juha Oksa, Ducharme, & Rintamäki, 2002). The cooling of the tissues leads to discomfort, deterioration of performance and finally to work accidents (Mäkinen & Hassi, 2009).

There is a need to increase the quantity and quality of studies dealing with the effects of exposure to cold thermal environment on physical working performance. Although cold thermal environment is known to influence performance in all working activities, its real influence is unknown and requires further investigation. The aim of this work is to contribute with a short review on physical working performance of humans exposed to cold thermal environment, by classifying different studies conducted in that area.

2 METHODS

2.1 *Searching strategy*

The academic and clinic PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses was used in creating and modeling of this article (Liberati et al., 2009). References were managed using Mendeley.

The process of creating the database of papers related to the area of cold thermal environment was divided into searching methods. The first searching method was to the Meta Search of databases. Access/login for searching databases was attempted by using the institutional IP address or University of Porto federate credentials. For searching purposes, keywords were defined, afterward to be expanded to expressions and terms created by their combination as follows: "cold environment & ergonomic",: "cold environment & health problems", "low temperature & health problems", "occupational disease & cold environment", "professional disease & cold environment" and "cold environment & biomechanics".

After defining keywords combinations to use in queries, two electronic database types were

Table 1. Selected articles: the summary in order of level of evidence, with main data and characteristics.

Reference/year	Subjects	Gender/age	Temperatures	Conclusion
1. (Wiggen et al., 2011)	12	Male/mean 23	22ºC, 5ºC, −5ºC, −15ºC, −25ºC	During low work intensity the current protective clothing at a given cold exposure leads to lowered body and skin temperatures, especially in the extremities, and to reduced manual performance when wearers are exposed to ambient temperature conditions of −5ºC or lower. Finger temperature was found to be an important indicator of hand and finger dexterity. The study suggests that a finger skin temperature below 20ºC result in impaired manual performances.
2. (Muller et al., 2011)	14	Male/mean 21	5 ± 1ºC	Finger temperature influence subjective perception of pain and lower manual performance in moderate cold.
3. (Leppäluoto et al., 2014)	6	Male/mean 21	10ºC	When the cold air exposures were repeated daily, thermal sensations became habituated first. Hand, foot, and general thermal sensations already became warmer after the first exposure.
4. (Chen, Shih, & Chi, 2010b)	24	Male and female/mean 25, 24 years	34°C water and 11°C water	Gross and fine hand dexterity, grip strength, and muscular activity were found to be positively correlated to skin temperature.
5. (Clark & Jones, 1962)	30	*n.a.	−12ºC	There appeared to be three sets of factors influencing the warm-up scores: the inhibition resulting from 2 days without practice; the mechanical facilitation associated with warm flexible hands; the inhibition produced by changing the thermal aspect of the stimulus complex eliciting the manual responses.
6. (J Oksa et al., 1997)	8	Male/mean 31 years	27ºC, 20ºC, 15ºC and 10ºC	Low level of cooling was sufficient to decrease muscle performance. The results showed a dose-dependent response between the degree of cooling and the amount of decrease in muscle performance.
7. (Holewijn & Heus, 1992)	9	Male/18–24 years	15ºC water and 40ºC water	There is a significant reduction in isometric force due to cooling of the muscle. Cooling the arm at 15ºC reduced the maximal grip frequency by 50%. Cooling the muscle did not affect endurance time compared to that at 32ºC.
8. (Ozaki et al., 2001)	13	Male/ mean 20 years	20ºC, 10ºC −25ºC,	Exposure to severe cold at night had an asymptomatic effect on workers that decreased both their rectal temperature and their manual performance.
9. (Juha Oksa et al., 2002)	8	Male/mean 31 years	25°C and 5°C	Forearm blood flow during systemic cooling was significantly lower. Repetitive work in the cold causes higher muscular activity and fatigue of forearm muscles than in thermo-neutral conditions.
10. (Chi, Shih, & Chen, 2012b)	24	Male and female/mean 25 and 24 years	34ºC water and 11ºC water	Finger skin temperature dropped about 20ºC after 40 min of cold immersion at 11ºC, and cold adaptation ceased the perceived discomfort even when the hand skin temperature, the **MVC declined further. On the other hand, warm immersion increased the skin temperature, muscular activity, and the MVC. The MVC resumed its baseline after 5 minutes of warm immersion which indicated full recovery of muscle fatigue.

*n.a.—not applicable.
**MVC—maximal voluntary contraction.

searched: "E-Journal" and "Index". In addition to the Meta Search, databases Informaworld (Taylor and Francis) and MEDLINE were searched thoroughly by using keywords and expressions: "cold" crossing with other keywords "musculoskeletal", "MSD", "knee injury", "shoulder injury", "lower back injury", "neck injury", "wrist injury", "hand injury", "elbow injury", and: "cold temperature" and "cardiovascular", "heart" and "cold temperature", "food industry" and "cold temperature", "construction industry" and "cold temperature", "cardiovascular disease" and "cold temperature". In addition, databases "PubMed", "PsycArticles" and "BioMed Central Journals" were searched thoroughly by using keywords and expressions: "cold exposure" crossing with the keyword "work".

2.2 *Inclusion criteria*

Articles were eligible if they met the criteria of being related with physical working performance in cold thermal environment. Articles published before 2000 were not considered in the Meta search, although articles found as references of chosen articles, that were published before 2000 and were strongly connected with the objective were included. Only articles published in English language were included.

3 RESULTS

In the identification process, the Meta Search resulted with 7349 articles, searched through electronic databases: IEEE Xplore, Informaworld (Taylor and Francis), PubMed, SCOPUS and Web of Science. The review of articles identified through database searching was restricted to articles published after 2000. Repeated articles and articles without an author name were excluded. Afterward, 2364 articles were excluded by screening articles titles. If article's abstracts were not related with physical working performance in cold thermal environment, they were excluded. Additional searching process was conducted by using Google Scholar, through which 45 more articles were found.

In total, 90 articles were assessed in a full-text version and screened thoroughly. Full-text articles were excluded if they were not related to physical working performance in cold thermal environment; if abstracts didn't have crucial parts as background, objective, methodology, results, discussion and conclusion; if objectives were not well defined; if the experimental methodology was not enough specified; if conclusions were made without any connection to experiment outcomes.

Finally, 10 articles were included in this short review, shown in the Figure 1. Included articles were

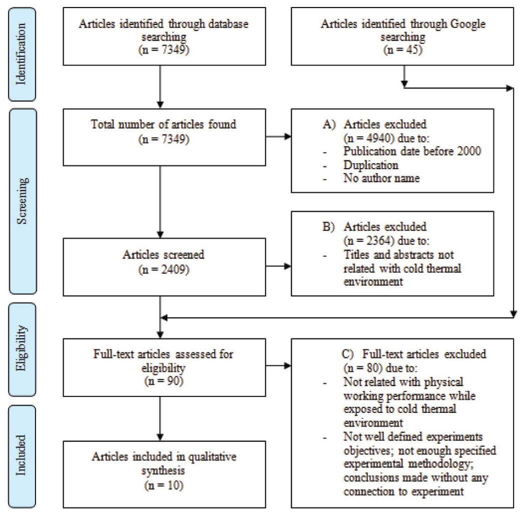

Figure 1. Selection of studies: summary of studies in order of level of evidence, with extracted data.

published between 1962 and 2014. Main results of this short review are shown in the Table 1.

4 DISCUSSION

Exposure to cold air temperatures was found to reduce physical working performance, increasing fatigue and lowering performance of muscles (Muller et al., 2011; J Oksa, Rintamäki, & Rissanen, 1997; Juha Oksa et al., 2002; Ozaki, Nagai, & Tochihara, 2001), reducing maximal grip frequency (Holewijn & Heus, 1992), hand and finger dexterity and grip strength which leads to impaired manual performance (Chen, Shih, & Chi, 2010a; Chi, Shih, & Chen, 2012a; Wiggen, Heen, Færevik, & Reinertsen, 2011) and maximal voluntary contraction (Chi et al., 2012a).

While it could be understandable to have just male volunteers for some industries and working activities such as for example the construction industry, there are many industries where a high percentage of female workers is found, such as in the food industry. Therefore, there is a need to conduct experiments considering both genders and differently aged groups. Although cold thermal environment is known to influence physical performance, its real influence is unknown and requires further investigation. More experiments should be conducted in different cold thermal environment temperatures, with different relative humidity and air movement (moderate and severe cold), and considering different tasks, on non-habituated and on habituated subjects, both genders, differently aged and physically healthy subjects (without bias factors mentioned in the section "limitations") for making consistent conclusions on physical performances while exposed to cold thermal environment.

5 LIMITATIONS

This study has several limitations. One of them is that not all of the bias factors were taken into consideration in chosen articles: sleeping hours, alcohol consumption, eating spices food, drinking coffee and tea, physical exertion, medicine taking and smoking cigarettes. Controlling those biases might improve results and therefore conclusions from the experiments. The phase of the menstrual cycle of female volunteers was not taken into consideration. A common limitation relies on voluntary participation, due to self-selection of the study members.

6 CONCLUSIONS

The findings of this short review indicate that moderate and severe cold thermal environment reduces skin body temperature and therefore physical working performance, lower muscle performance, maximal grip frequency and grip strength, hand and finger dexterity, maximal voluntary contraction, while increase muscle fatigue. Experiments should be conducted on non-habituated and on habituated subjects, taking in consideration different tasks, both genders, differently aged subjects, with different time exposure in order to get consistent conclusion on physical performances.

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Appendix 6 – Paper 2

Occupational Safety and Hygiene III – Arezes et al. (Eds)
 ISBN 978-1-138-02765-7

Changes in face and hands skin temperatures during exposure to moderate cold thermal environment

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ABSTRACT: Exposure to cold thermal environment was found to be a significant risk factor in industrial activities. The aim of this study was to simulate a repetitive cheese packing movement in a laboratory environment and investigate the influence of moderate cold on changes in hand and face skin temperature. Thermographic images were taken after ten and thirty-five minutes of exposure, in order to evaluate the influence cold on volunteers. Five volunteers were exposed to moderate cold and seven to thermoneutral temperature. All volunteers were female and in the first phase of the menstrual cycle. The findings of this investigation show that there is a big difference in skin temperatures between the left and right hand. Further investigation should be conducted in different cold thermal environment conditions, considering moderate and severe cold, considering both genders, but always considering the follicular phase when dealing with female volunteers.

Keywords: face and hands temperature changes; moderate cold exposure; thermography

1 INTRODUCTION

Exposure to cold thermal environment is a significant risk factor in industrial activities, present in outdoor during the winter season and indoor present in all seasons (Tochihara, 2005). Indoor exposure is mostly related to working activities in the fresh food industry with temperatures from 0 to 10ºC and frozen goods at temperatures below –20ºC, while cold exposure in outdoor activities is present in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work and related occupations (Mäkinen et al., 2006). Outdoor exposure to cold is of particular interest for regions in high latitude environments where winter seasons last for several months (for example Finland with winter lasting for 3–7 months (Mäkinen, 2007). The degree of exposure to cold is dependent on several factors such as occupation, gender, age, health, exercise activity, and education (Mäkinen, 2007). Acclimatization to cold benefits on some aspects such as: norepinephrine response, hemoconcentration, and, in lesser amounts, skin temperature and systolic blood pressure (Leppäluoto et al., 2014). Decreasing of the body temperature resulted in increasing of the muscular strain which led to musculoskeletal disorders (Oksa, Ducharme, & Rintamäki, 2002), cooling of the tissues led to discomfort, deterioration of performance, work accidents (Mäkinen & Hassi, 2009) and increased likelihood of reporting low back symptoms (Dovrat & Katz-Leurer, 2007).

When exposed to cold temperatures, the body attempts to preserve the normal temperatures of vital internal organs. The first reaction is the blood flow diminution in the extremities. Therefore, hands should be measured in subjects' exposure to cold. To compare, face temperature changes should also be measured.

The infrared thermal imaging is often used to investigate changes in skin surface temperature distribution and to monitor the physiology (Autonomous nervous and microvascular systems) in real time for clinical assessment purposes (Ring & Ammer, 2012). Therefore, thermography was used in this experiment.

The cheese industry is a food industry where regulations imply that the air temperature should be below 10°C. Equipment and resources influenced the decision to conduct the experiment with the simulation of a cheese packing process, with moderate cold air temperature.

The aim of this study was to simulate and evaluate a working activity in a cheese industry and investigate the influence of moderate cold on changes in hand and face skin temperature.

The objective is to investigate face and hands temperature changes between.

- 10 min of exposure to cold (after a ten minutes habituation, before conducting the cheese packing task)
- 35 min of exposure to cold (after a ten minutes habituation, fifteen minutes cheese packing activity and ten minutes rest while being exposed to cold)

2 METHODS

2.1 *Subjects*

Five right handed female volunteers participated in this study. Their (mean ± SD) age was 23 ± 3.85 years old, mean body height was 165 ± 3.67 cm, mean weight was 58.5 ± 5.38 kg, mean body mass was 21.40 ± 1.81. All the volunteers were in a first phase (follicular phase) of the menstrual cycle, as it was found to be an important factor especially for the level of the body temperature (Janse de Jonge, 2003). The subjects were fully informed of the nature and purpose of the experiment, as well as the possible discomforts and risks involved discomforts. A written consent to participate in the experiment was read and signed by all subjects. Before the experiment started, nine questions were asked to the volunteers in order to evaluate possible bias factors. The questions related to medicine taking were regarding to any type of medicine, even if it was a headache pill. Furthermore, physical exertion was evaluated as –1 is the person conducted physical exertion less than usual in the last 12 hours, 0 for physical exertion as usual and +1 if the physical exertion was higher than usual. The menstrual cycle phase was checked by a telephone call prior to the volunteer's arrival.

2.2 *General experimental design*

When the volunteers arrived to the laboratory, their weight and height were measured; they answered questions related to their consuming, sleeping and physical exertion. After spending 20 minutes in the laboratory room with an air temperature from 25.6 to 25.9°C and relative Humidity (Hr) of 42–43%, they entered the climatic chamber. In the climatic chamber, air temperature was 10°C and relative humidity 30% during the cold temperature exposure, and 20°C and 30% Hr (control test) during the comfort temperature exposure. Each volunteer was once exposed to each thermal condition, once at a time. All volunteers were dressed in the same way. After entering the climatic chamber, the volunteers were asked to sit and perform a coin dexterity test for three times. The volunteers were considered to be stabilized after ten minutes, so the thermographic images were taken. Afterward, the volunteers were asked to sit once again, and put their hands on a carton box (used as a table) from which hands were photographed with a thermography camera. Volunteers' faces were photographed too. Fifteen minutes after the volunteers entered the climatic chamber, they were instructed how to perform a simulation of a repetitive work normally used in a cheese packing industry, performing it for the next fifteen minutes in a standing posture. The work was based on packing 1 kg of sand bag (simulating cheese packing process). The sand bag was located on the front-left side of the volunteers. The bag was taken by the volunteers with the left hand and put on a newspaper located in front of the volunteers and packed by using two hands into the newspaper, afterward to be taped by using the right hand. When the bag was packed, it was put on the front-right side of the volunteers by using both hands. At the end, 35 minutes after being exposed to the environmental air temperature, the second thermographic recording and dexterity tests took place again. The volunteers left the climatic chamber in total approximately 40 minutes after entering.

2.3 *Thermography*

Thermographic images were taken with the infrared camera FLIR A325 (resolution of 320 × 240 pixels, accuracy of ±2% of the overall reading and sensitivity of 0.05°C) and by using the ThermaCAM Researcher Professional 2.10 program. Thermographic images were processed by using the program ThermaCAM Researcher Professional 2.10. Temperature range was set from 15°C to 34°C. The thermography camera was turned on at least 30 minutes prior to taking images. Images were taken for two times: 10 minutes and 35 minutes after the volunteer entered the climatic chamber as it is illustrated on Figure 1.

Two images were taken each time: of both hands placed on the carton box (table) and the front part of the face from a distance of ~ 0.5 m.

On the figure 2, examined sections of the hands and face are illustrated.

2.4 *Control test*

For the control test eight volunteers were assembled (of which five were the same as in moderate cold tests). They were exposed to air temperature 20ºC and 30% Hr in a controlled environment (climatic chamber), conducting same tasks and by the same timetable as for the moderate cold test.

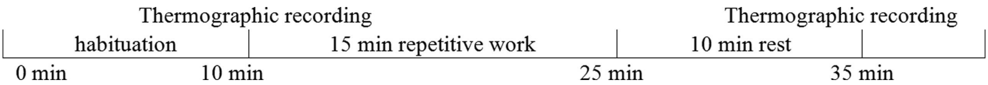

Figure 1. Diagram showing how the experiment was organized.

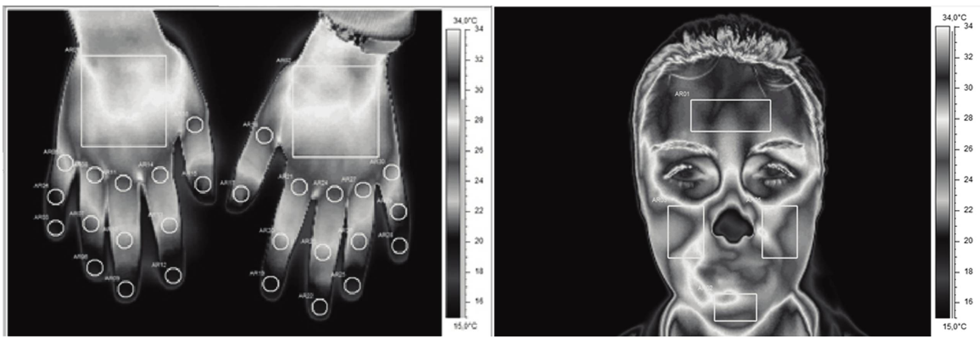

Figure 2. Examined sections of the hands and face.

2.5 *Biases*

There are several potential bias factors to consider. One bias factor was related to the volunteers evaluated, there were 5 volunteers for moderate cold test, which is a low number. When conducting an experiment in moderate cold, one volunteer consumed alcohol in the last 12 hours, prior to the test, which might have influenced the results.

3 RESULTS

3.1 *Thermography test*

One volunteer's results from the control test were not included in this paper as there were many bias factors (smoker, drink alcohol in the last 12 hours and sleeping for 2 hours during the night). When conducting an experiment on comfort temperature, one volunteer consumed alcohol and coffee in the last 12 hours, one more consumed coffee, and one consumed coffee and smoke cigarettes. The results of the volunteer V8 were not included in this study for reasons mentioned in the section 2.4. In the table 2, results of the thermography test are shown for hands, forehead, right and left zygomat region (cheek) and chin when exposed to air temperature 10ºC and relative humidity 30%. As it is illustrated, skin temperature of all measured parts declined from 1.4ºC (forehead) to 3.3ºC (right hand). From all measured volunteers skin temperatures were analyzed, and an average was calculated with a standard deviation. The difference from the skin temperature of body parts taken after 10 minutes of being exposed to moderate cold air temperature and the temperature taken 35 minutes after is illustrated in °C in the last column. In the table 1, thermography results of volunteers exposed to air temperature 20°C and relative humidity 30% are shown.

On figure 3, thermographic images of hands taken after 10 and after 35 minutes of exposure to air temperature 10ºC and 30% of relative humidity are illustrated, and on figure 4, thermographic images of the front part of the face taken after 10 and 35 minutes of exposure to air temperature 10°C and 30% Hr are illustrated.

4 DISCUSSION

While at the start point (10 minutes after being exposed) there were no significant differences in skin temperature of the left and the right hand, there is an almost 1.5°C difference in hand skin temperatures after 35 minutes of exposure. As all the volunteers were right handed, it was not possible to investigate if there was an effect on handiness. Potential bias might be laying in the working activity, which needs to be explored better. Using more one hand than the other (more left than the right) as it was described in the section "General experimental design".

Touching the cold product might have influenced the results as it might have cooled one hand more than the other, which was not found in the experimental results. In the table 3, differences in skin temperatures of different body parts considering the air temperature and exposure time are illustrated. Skin temperatures varied by 2.6°C (hands) and by 2.8°C (forehead) after 10 minutes

Table 1. Thermographic results from the experiments.

Air temperature and relative humidity	10°C and 30%				20°C and 30%			
	Exposure (min)	Average t (°C)	s.d.	Difference (°C)	Exposure (min)	Average t (°C)	s.d.	Difference (°C)
Right hand	10	28.16	± 0.97	3.30	10	30.80	± 1.22	0.31
	35	24.86	± 1.30		35	30.49	± 1.24	
Left hand	10	28.14	± 0.96	1.76	10	30.74	± 1.41	0.09
	35	26.38	± 0.76		35	30.83	± 1.27	
Forehead	10	30.78	± 0.65	1.40	10	33.58	± 0.46	0.00
	35	29.38	± 0.78		35	33.58	± 0.63	
Right zygomat region	10	28.58	± 0.99	3.08	10	32.45	± 0.67	0.89
	35	25.50	± 0.70		35	31.56	± 1.01	
Left zygomat region	10	28.42	± 1.00	3.14	10	32.35	± 0.65	0.84
	35	25.28	± 0.95		35	31.51	± 1.07	
Chin	10	29.26	± 0.92	3.12	10	32.79	± 0.73	0.48
	35	26.14	± 0.99		35	32.31	± 1.05	

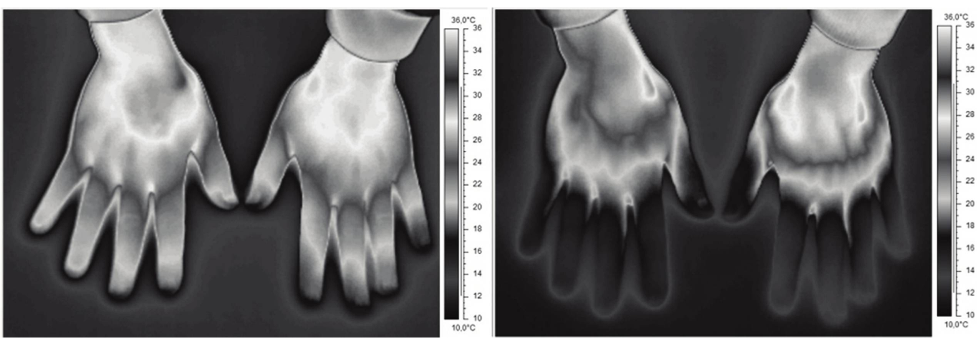

Figure 3. Thermographic images of hands after 10 minutes and 35 minutes of exposure to air temperature 10°C and relative humidity 30%.

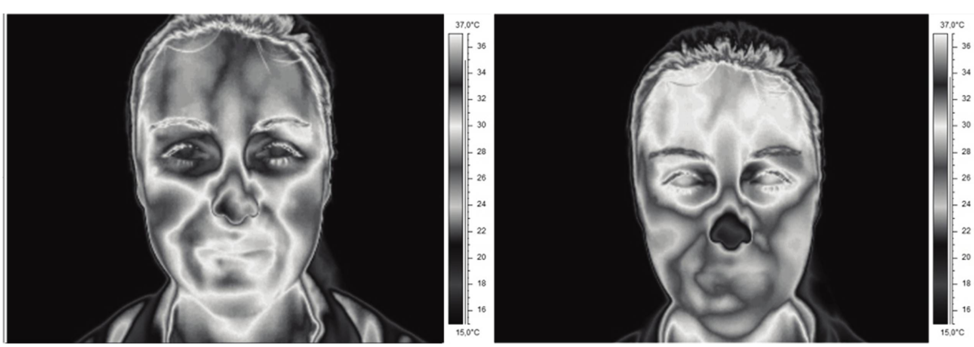

Figure 4. Thermographic images of the front part of the face after 10 minutes and 35 minutes of exposure to air temperature 10°C and relative humidity 30%.

of exposure, in between exposure to air temperature 10°C and 20°C. In the same way, skin temperature of the right and left zygomat region and chin varied from 3.5 to 4°C.

After exposure of 35 minutes, the difference become bigger, for the right hand 5.6°C, left hand 4.5°C, forehead 4.2°C and right zygomat region, left zygomat region more than 6ºC. Further investigation should be conducted on longer period exposure to 10°C, as for example for air temperature 4°C and relative humidity 80%, which is regulated for the similar food industries, as it is for example the meat industry (ISO, 2002). Thermography tests should be conducted in different cold thermal environment conditions, considering moderate and severe cold, considering both genders, but always considering the follicular phase when dealing with female volunteers. For statistically significant and consistent results, a larger group, with both handiness volunteers should be included in further experiments of this type.

5 CONCLUSIONS

The findings of this investigation show that there is a big difference in skin temperatures between the left and right hand when exposure to cold, when conducting a repetitive cheese simulation. While at the start point (10 minutes after being exposed) there were no significant differences in skin temperature of the left and the right hand, there is an almost 1.5ºC difference in hand skin temperatures after 35 minutes of exposure. The right hand was found to get colder after exposure to environmental conditions and while conducting a cheese packing process. In between exposure to air temperature 10ºC and 20ºC, skin temperatures varied by 2.6ºC (hands) and by 2.8ºC (forehead) after 10 minutes of exposure. After exposure of 35 minutes, the difference become bigger, for the right hand 5.6ºC, left hand 4.5ºC, forehead 4.2ºC and right zygomat region, left zygomat region more than 6ºC. Thermography tests should be conducted in different cold thermal environment conditions, considering moderate and severe cold, considering both genders, but always considering the follicular phase when dealing with female volunteers. A larger group of volunteers should be included in further experiments of this type. Further investigations should be conducted regarding volunteer's subjective analysis, points of view and sensations during the simulation.

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Appendix 7 – Paper 3

U.Porto Journal of Engineering, 1:1 (2015) 114-121
ISSN 2183-6493

Received: 3 February, 2015
Accepted: 23 February, 2015
Published: 1 October, 2015

Cognitive Working Performance in Moderate Cold Thermal Environment: a systematic review

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Abstract
Presence of cold thermal environment represents significant risk factors high latitudes, during winter seasons and in a large number of industrial activities, influencing the cognitive working performance. The aim of this work is to contribute with a systematic review on cognitive working performance in moderate cold thermal environment, by classifying different studies conducted in that area. By using appropriate keywords and searching electronic databases, a systematic review of English articles has been conducted. Only articles related to cognitive working performance in moderate cold thermal environment were included. Nine experimental articles were included. The number of participants varied from 6 to 22 subjects. The findings of this systematic review indicate that moderate cold environment influence the cognitive performance by decreasing working performance, reaction time, executive function and attention and it remain decreased for some time after cold exposure, even when the core and skin temperature get stabilized.

Subject Headings. Occupational health, Storage of food.
Author Keywords. Occupational safety and health, Mental performance, Cold temperature, Food industry.

1. Introduction

Cold thermal environment is present in high latitude environments (Mäkinen 2007), in outdoor during the winter season and indoor present in all seasons (Tochihara 2005). Indoor exposure is mostly related to working activities in the fresh food industry with temperatures from 0-10°C and frozen goods at temperatures below -20°C, while cold exposure in outdoor activities is present in occupations such as marine, army, agriculture, forestry, mining, factory work, construction work and related occupations (Mäkinen, Raatikka, et al. 2006).

The degree of exposure to cold is dependent on several factors such as occupation, gender, age, health, exercise activity, and education (Mäkinen, 2007).

Moderate cold impairs performance on tasks of low physical activity and requiring concentration and vigilance. These are for example cognitive performance and postural control. Some positive effects of moderate cold exposure on cognition may also occur, reflected as shorter response times and improved accuracy (Mäkinen 2007).

The phase of the menstrual cycle was found to be an important factor when conducting experiments on female subjects, as the level of the body temperature has high differences between the follicular and the luteal phase. Therefore, female subjects should be always in the first phase (follicular) of the menstrual cycle (Janse de Jonge 2003).

Although some aspects of the influence of moderate cold thermal environment on cognitive working performance are known, there is still a need to increase the quantity and quality of studies which approach this topic. The aim of this work is to contribute with a systematic review on cognitive working performance in moderate cold thermal environment, by classifying different studies conducted in that area.

2. Materials and Methods

The academic and clinic PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was used in creating and modeling of this article (Liberati et al. 2009). References were managed using Mendeley.

2.1. Searching strategy

The process of creating the database of articles related to the influence of cold thermal environment on human fatigue and performance was divided into searching methods. The first searching method was the Meta Search of databases in the area of engineering, health and the multidisciplinary area. Access/login for searching databases was attempted by using the institutional IP address of University of Porto federate credentials. For searching purposes, keywords were defined: “cold human performance”, “cold human effect”, “cold human influence” and “cold human fatigue”.

After keywords were defined, two electronic database types (“E-Journal” and “Index”) were searched by title, without using quotation marks on keywords, in order to allow a different order of words in the title.

In addition to the Meta Search, databases in the engineering (“Compendex”, “Inspec”, “IEEE Xplore” and “ScienceDirect (eJournals)”), health (“MEDLINE (EBSCO)”, “PsycArticles”, “PubMed”, “BioMed Central Journals”, “nature.com” and “Science Magazine”) and multidisciplinary area (“Current Contents”, “Web of Science”, “SCOPUS”, “Informaworld (Taylor and Francis)”, “SpringerLink”, “Directory of Open Acces Journals (DOAJ)”, “Emerald Fulltext”, “Oxford Journals”, “SAGE Journals Online”, “Wiley Online Library” and “Cambridge Journals Online”) were searched thoroughly. In total, 21 databases were searched thoroughly by title, using same keywords as for the Meta Search.

All articles that were connected with the topic to the chosen articles were screened, and if connected with the systematic review objective, they were downloaded. Articles that were citing the chosen articles were also screened and if relevant included in this systematic review.

2.2. Inclusion criteria

Articles were eligible if they met the criteria of being related with the influence of cold thermal environment on human cognitive fatigue. Articles published before 2000 were not considered in the Meta search and search through databases in engineering, health and multidisciplinary area. Only articles published in English language and that were free for downloading by using the University of Porto federate credentials were included.

3. Results

In the identification process, the searching process resulted with 198 articles, of which 181 were published after the year 2000, all in English language. Repeated articles were excluded which resulted with 138 articles to consider. By screening article titles additional 4 articles were excluded which resulted in a total of 134 articles to consider. By screening article abstracts additional 18 articles were excluded which resulted with a total of 116 articles to consider. Additional 27 articles were excluded due to being a review, questionnaire, report or a cross-sectional study, which led to a total of 89 research articles. By excluding articles considering the influence of cold thermal environment on physical performance, additional 78 articles were excluded, which led to 11 articles on the influence of cold thermal environment on human cognitive fatigue and performance. These articles were assessed in a full-text version and screened thoroughly.

Full-text articles were excluded if they were not related to cognitive working performance in moderate cold thermal environment; if abstracts didn't have crucial parts as background, objective, methodology, results, discussion and conclusion; if objectives were not well defined; if the experimental methodology was not enough specified; if conclusions were made without any connection to experiment outcomes.

Finally, 8 articles were included in this short review, shown in the Figure 1. Included articles were published between 2000 and 2012, as only those articles passed the selection criteria.

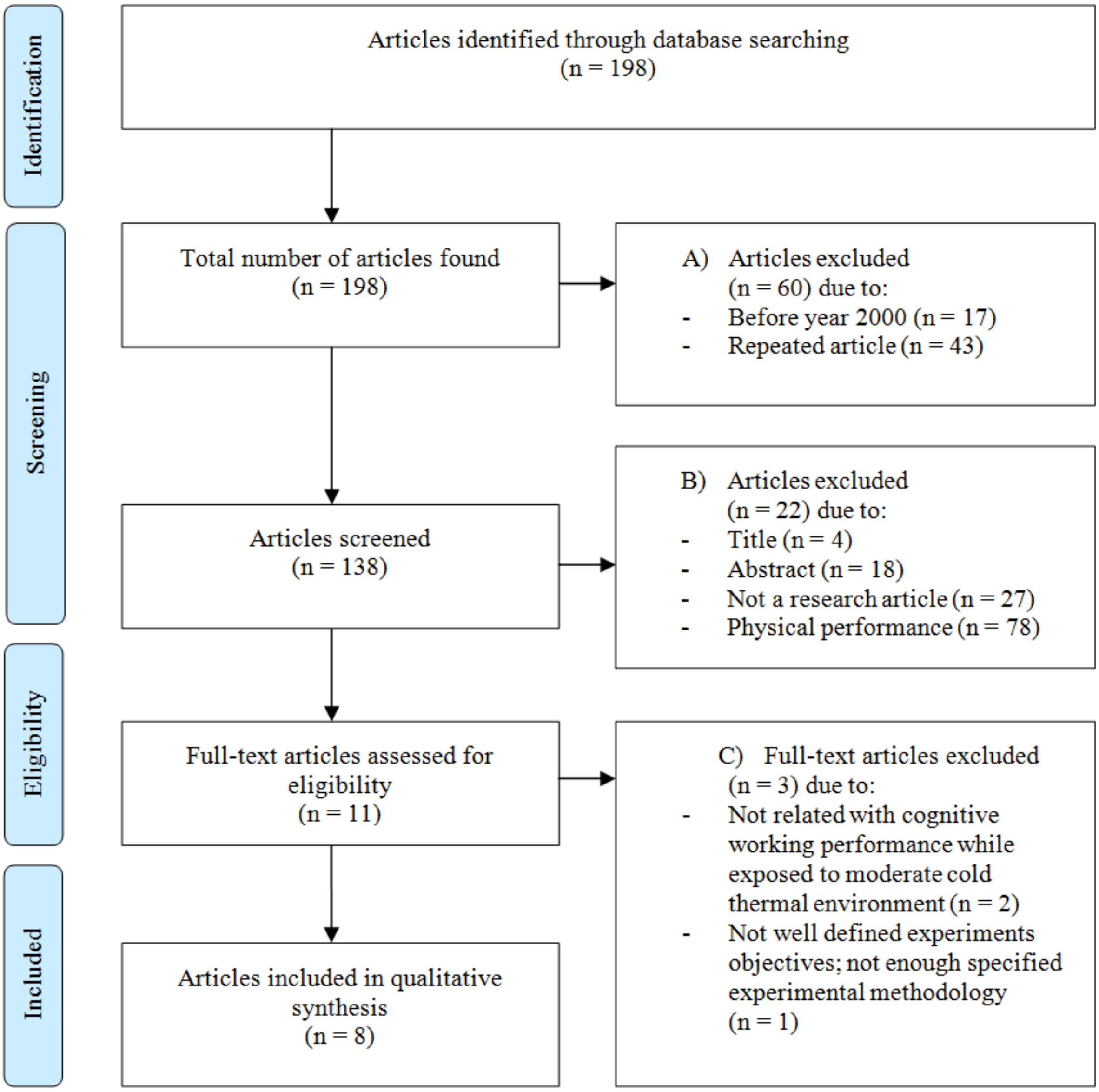

Figure 1: Selection of studies: summary of studies in order of level of evidence, with extracted data

Main results of this systematic review are shown in the Table 1 and Table 2.

Reference/Year	Subjects/Gender	Mean Age (years)	Mean Height (cm)	Mean Weight (kg)	Mean Body fat (%)
1. (Muller et al. 2012)	10 men	23±1	183±6	85±5	11±4
2. (Spitznagel et al. 2009)	6 men	23.3±1.5 (range 22-26)	182.7±10.8 (range 168.7-198.0 cm)	85.2±6.7 (75.2-95.2)	11.1±6.1 (range 5.4 – 18.3)
3. (John Paul et al. 2010)	22 men and 1 women	39.13±9.35			
4. (Mäkinen, Palinkas, et al. 2006)	10 men	22.5±1.6	180.8±7.2	72.4±7.3	17.1±1.9
5. (Adam et al. 2008)	6 men and 2 women soldier	24±6 yr	170±6	72.9±11.1	22±6
6. (Cheung, Westwood, and Knox 2007)	14 men and 6 women	22.9±4.5 (men) and 24.2±6.0 (women)		74.9±7.1 (men) and 63.1±8.2 (women)	11.4±4.4 (men) and 19.5±2.8 (women)
7. (Muller et al. 2011)	11 men	21±1			17±6
8. (Hartley and MCcabe 2001)	10 men and 10 women	21.75±2	173.55±8.32	71.24±10.97	17.93±4,50

Table 1: Selected articles: the summary in order of level of evidence, with main data and characteristics

Reference	Exposure Temperature	Exposure Time	Type of Work	Cognitive Measurements	Other Measurements
1.	10°C and 25°C (air)	3x (120 min to 10°C and 120 min to 25°C)	sitting	integneurotm, digit span, choice reaction time, executive maze task	skin and rectal temperature, thermal sensation, oxygen consumption
2.	10±0.5°C and 25°C (air)	3x (120 min to 10°C and 120 min to 25°C)	sitting and completing cognitive tasks on the pc	choice reaction time, stroop test "color-word", the mazes task	
3.	average -5°C (summer) average -24°C (winter) room 18-22°C (air)	14 months (examinations at the 2nd month, 7th month and 12th month)	sitting and performing cognitive tests	task acquisition, recognition memory, delayed recognition, attention and concentration, short-term memory, digit symbol substitution, learning and memory from evaluating the accuracy of response	
4.	10±0.3°C and 25±0.3°C (air)	1x (90 min to 25°C and 120 min to 10°C)	sitting and performing cognitive tests	automated neuropsychological assessment metric for isolated and confined environments	skin and rectal temperature, finger skin temp, thermal sensation, oxygen consumption, systolic and diastolic blood pressure, heart rate
5.	2°C, 20 and 45°C (air)	1x (60 min to 20°C, 60 min to 45°C and 50 min to 2°C)	sitting and cycling	sentry duty performance (simulation weaponeer), nasa-tlx and poms questionnaire	skin and rectal temperature, oxygen consumption, the cold strain index was calculated
6.	18–25°C (water)	60-90 min (until rectal temperature drop 1.08°C)	sitting while head-out immersion in cool water and performed the attention test	vigilance test, spatial attention test	skin and rectal temperature, finger dexterity, heart rate
7.	5±1°C and 25–27°C (air)	30 min to 25-27°C, 120 min to 5±1°C and 60 min to 25-27°C	sitting and watching the tv	poms questionnaire, total mood disturbance was calculated, scwt test	skin and rectal temperature
8.	0±2°C and 18±2°C (air)			stroop word-colour test, working memory test, signal detection task, fitts' task	core temp, mvc/force output

Table 2: Selected articles: the summary in order of level of evidence, with main data and characteristics

4. Discussion

Exposure to moderate cold thermal environment was found to decrease the reaction time and executive function (Muller et al. 2012; Spitznagel et al. 2009; Mäkinen, Palinkas, et al. 2006; Adam et al. 2008), and decreasing in attention (Spitznagel et al. 2009; Mäkinen, Palinkas, et al. 2006; Adam et al. 2008; Cheung, Westwood, and Knox 2007; Muller et al. 2011; Hartley and MCcabe 2001). The cognitive working performances experimented by included articles are shown in the Table 3:

Reference	Working Memory	Long-term Memory	Short-term Memory	Reaction time	Executive function	Attention	Accuracy	Mood
1.	Decreased			Decreased	Decreased			
2.				Decreased	Decreased	Decreased		
3.		Increased	Same					
4.			Same	Decreased	Same	Decreased	Increased	
5.				Decreased	Decreased	Decreased		Decreased
6.						Decreased		
7.						Same		Decreased
8.	Decreased					Decreased		

Table 3: The cognitive working performances experimented by included articles

One study found that cognitive dysfunctions persist for some time after the cold exposure and despite the stabilization of the core and skin temperature and thermal sensation (Muller et al. 2012). The additive effect of sleep deprivation to cold exposure was found in basic attention, reaction time and functioning, where it was generally worsened in the presence of both, relative to cold exposure alone (Spitznagel et al. 2009).

Major dispute among the included articles were on the influence of cold thermal environment on memory. While two articles found working memory to generally decrease (Muller et al. 2012; Hartley and MCcabe 2001), some articles found short-term memory to stay the same even after exposure (John Paul et al. 2010; Mäkinen, Palinkas, et al. 2006) and one of them found long-term memory to increase (John Paul et al. 2010).

Some of the less investigated cognitive parameters were accuracy, which was found to be higher in cold environment by one author (Mäkinen, Palinkas, et al. 2006) and mood, which was found to be decreased when exposed to cold thermal environment (Adam et al. 2008; Muller et al. 2011). Additional experiments should be conducted in order to get consistent results on the influence of cold environment on accuracy and mood.

Most articles excluded female subjects in order to eliminate potential confounds of hormonal fluctuation on thermoregulation, some are presented in this systematic review. However, there are many industries with moderate and severe cold thermal environment, where a high percentage of female workers could be usually found (e.g. the food industry). As it was concluded by some previous research (Janse de Jonge 2003), high differences were found in females between the follicular and the luteal phase of the menstrual cycle. Therefore experiments of the influence of cold on cognitive performance of females need a further research in order to get additional information on monthly changes and possibly adapt the working schedule of female workers according to their menstrual cycle phases. By doing that a higher production and a lower level of health and safety risks might be achieved. There are several articles conducting experiments on both genders (Hartley and MCcabe 2001; Cheung, Westwood, and Knox 2007; Adam et al. 2008; Man and Omel 2008;

John Paul et al. 2010), but it is also noticeable that for most of them the number of female subjects is much lower than the number of male subjects (John Paul et al. 2010; Adam et al. 2008; Cheung, Westwood, and Knox 2007).

More laboratory and industrial experiments should be conducted in order to further the knowledge on the influence of cold thermal environment on cognitive performance. Experiments should be conducted in different cold thermal environment temperatures, with different relative humidity and air movement speed. Different tasks should be considered using physically healthy subjects of both genders but differently aged groups. Experiments should be conducted on non-habituated and habituated subjects in order to make consistent conclusions on cognitive performances while exposed to cold thermal environment.

5. Limitations

This study has several limitations. Most of the chosen articles did not considered several bias factors which might had influenced the subject physical and therefore immediately cognitive results: number of sleeping hours; smoking cigarettes; consumption of alcohol, tea or coffee at least 12 hours prior to the test; how much and which kind of food the subject ate; the phase of the menstrual cycle; illness history; medical control; medicine taking or physical exertion at least 12 hours prior to the test. Controlling those biases might have improved results and therefore conclusions from the experiments. One of the limitations was using only the institutional IP address of the University of Porto, therefore the search was limited to databases on which the university was subscribed to. Limiting the review to articles published after the year 2000 might have excluded some articles which might benefit to this systematic review.

6. Conclusions

The findings of this systematic review indicate that moderate cold thermal environment decrease cognitive working performance, particularly reaction time, executive function and attention, while there is still a dispute on the influence of cold on the working memory, depending on short-term or long-term exposure. It was found that cognitive performance remained affected for some time after cold exposure, even after the core and skin body temperature were stabilized. The influence on mood and accuracy was found not to be very investigated. There is a certain number of limitations for this systematic review, as included articles in most cases didn’t considered bias factors which were mentioned in the section limitations. Further experiments should be conducted on the cognitive working performance in moderate cold thermal environment, considering different air temperatures, including both genders and differently aged subjects in order to get results of greater quality and consistency.

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Appendix 8 – Paper 4

Influence of Cold Thermal Environment on Packing Workers from the Frozen Food Processing Industry

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ABSTRACT: In the fresh food industry the working activities are conducted in environmental temperatures from 0ºC to 10ºC, while in the frozen food industry usually are at temperatures below -20ºC which influences the variations in core and skin body temperatures and affects the working performance, health and safety of the employees. The aim of this work is to contribute with a study on the influence of cold thermal environment on core and skin body temperatures in packing workers from the frozen food industry. By using the core body pill sensor and 8 skin temperature sensors a study was conducted on 4 workers during 11 days. The lowest recorded temperature was for hand 14.09ºC, mean skin temperature had variations of 1.10 to 3.20ºC along the working period and the mean body temperature on two occasions decreased below 35ºC. The core temperature was found to increase. The mean body temperature showed small changes along the time.

1 INTRODUCTION

The frozen food deliver high quality, good value, safe foods with an extended storage life, helping the dietary portion control and reducing waste, offer the possibility to preserve and use seasonal foods all year round (Young et al. 2010). In emerging markets like Latin America, South East Asia and Eastern Europe, an increase demand for richer and more varied diets will occur and, importantly, increase demand for large domestic appliances such as freezers (Kennedy 2000). Further on, shifts in global economic, social and demographic trends will continue to put pressure on food supplies, as we already witness today, more frozen foods to be sold each year and new products introduced to swell the total sales (Artley, Reid, and Neel 2008). The structure of the labour market is constantly undergoing change, away from fresh and homegrown towards chilled and frozen food, and its future trend is shown clearly through the development in recent years (Baldus, Kluth, and Strasser 2012).

Indoor working exposure to cold offer constant and predictable climate conditions, which facilitates cold risk management and workers cold adaptation. The different types of cold adaptations are related to the intensity of the cold stress and to individual factors such as body fat content, level of physical fitness and diet. The hypothermic general cold adaptation seems the most beneficial for surviving in the cold but the interest of the development of general cold adaptation in workers in the cold are questionable since occupational activities can be organized to avoid cold disturbances (shelter, clothes, heat sources, time sharing). For the workers working in cold environments, adaptations of extremities are beneficial, as are developing cold induced vasodilation, improving manual dexterity and pain limits (Launay and Savourey 2009). Workers with less years of activity seem to be more satisfied with the cold thermal ambient than veterans with more than 10 years (Oliveira et al. 2014). Cold work involves several adverse health effects that are observed in indoor work. Many of these adverse outcomes may be further aggravated in persons having a chronic disease (Mäkinen and Hassi 2009).

Severe cold thermal environment (SCE) reduces skin body temperature (Tskin) and therefore physical working performance, lower muscle performance, maximal grip frequency and grip strength, hand and finger dexterity, maximal voluntary contraction, while increase muscle fatigue (Zlatar, Baptista, and Costa 2015). In cold, musculoskeletal complains and symptoms are common (Oksa, Ducharme, and Rintamäki 2002), which further on might lead to work accidents (Mäkinen and Hassi 2009). By a questionnaire conducted by Taylor, Penzkofer, Kluth and Strasser (Penzkofer, Kluth, and Strasser 2013), it was found that order-picking work in the cold leads to frequent complaints especially in the upper part of the body. Repeated, prolonged and chronic hyperpnoea with cold dry air represents a significant environmental stress to the proximal and distal airways, leading to the development of respiratory symptoms, airway hyper-responsiveness and injury, and inflammation and remodelling of the airway (Sue-chu 2012). When the human body is exposed to cold, the initial response is to preserve heat by reducing heat loss. The skin blood flow, especially in extremities is reduced by vasoconstriction (Charkoudian 2010), which leads to increased systolic and diastolic blood pressure, lowered heart rate and body temperature in extremities(Gavhed 2003). It is very well documented that there is an increase mortality related to acute myocardial infarction (AMI) during the cold season (Chang et al. 2004; Kriszbacher et al. 2009). Some authors considered fluctuation in air temperatures as a major influence on AMI and stroke, especially when it comes to sudden decrease in temperature in a 24-hour period (Gill et al. 2013). A 5ºC reduction in mean air temperature was associated with 7% and 12% increase in the expected hospitalization rates of stroke and AMI, respectively (Chang et al. 2004). On other hand, Kriszbacher suggested that beside temperature fluctuations, the barometric pressure and front movements greatly contributed to AMI cases (Kriszbacher et al. 2009). Nevertheless, cardiovascular diseases can be reduced by good management program of risk factors at work (Mitu and Leon 2011).

The objective of this work was to evaluate the influence of cold thermal environment on the core and skin temperature of packing workers in the frozen food processing industry.

2 METHODOLOGY

2.1 *General data*

The experiments were conducted in the cold packing sector from the frozen food processing industry. All the documents (informed consent, participation and trial forms, information for the volunteers) were translated into Brazilian Portuguese and reviewed and culturally adapted by a native Brazilian speaker. The experiment was approved by the Ethics Committee of the University of Porto, approval number: 06/CEUP/2015.

In table 1 is shown the outside environmental conditions at near the industry location, gathered by the National Institute of Meteorology (INMET), station of meteorology of Macau, Rio Grande do Norte, Brazil.

All workers usually spent their time in moderate cold thermal environment, conducting moderate to heavy physical work (packing 400 grams packages into 20 kg packages, check the stored material, organize materials on pallets, separate materials from pallets, move pallets and heavy loads with forklifts, once a week breaking the ice on the floors in SCE chambers and do heavy lifting). The only male with low intensity work was the volunteer number 1 which was the leader of logistics. The logistic leader had to delegate working tasks, control, supervise, and count packages. He was a connection between offices and the stock, therefore no heavy work was conducted, but still, in order to check the packages and organize them, his exposure to SCE was with greater intensity compared with other workers. Other volunteers selected to be fully monitored were male packing operators, spending mostly their time in moderate cold thermal environment, and several times per day storing frozen packages in the SCE chambers. The thermometer in the moderate cold sector was showing environmental temperature of 18±2°C, but as it was placed at 7 meters height, it was showing the highest room temperature. The workers were exposed to much lower temperature as they were working on a lower height, and they were located in front of SCE chambers with -25 to -30°C, which would cool the moderate cold sector each time the SCE chamber was opened.

Table 1. Outdoor air temperature, relative humidity and velocity data from the measuring days

	09:00	12:00	13:00	17:00
Mean temp. ±SD (°C)	25.1 ±0.84	29.3 ±1.48	29.8 ±2.13	29.7 ±2.00
Mean Relative Humidity ±SD (%)	87.8 ±3.86	68.0 ±9.95	67.0 ±11.81	67.0 ±11.00
Mean Air velocity ±SD (m/s²)	1.9 ±0.34	3.6 ±1.66	4.2 ±1.29	5.6 ±1.00

2.2 *Fully monitored workers*

Four workers from the cold packing sector were chosen to be fully monitored during their working activities. Three of them were screened during 3 working days, while one during 2 working days. In total, a sample of 11 measurements was achieved. The mean age±sd of the successfully fully monitored workers was 29±6.3 years old, mean body height was 167.4±5.4 cm, mean weight of all 11 measuring days was 79.7±17.9 kg, mean body mass index (BMI) was 28.4±6.3 kg/m². The medical examination was conducted by the industrial medical doctor. All subjects were informed about the goals and risks of the experiments, and signed the informed consent prior to participating. The subjects were examined and asked to drink the usual amount of coffee, tea, to avoid drinking alcohol for at least 12h before the test; not to eat spicy food at least 12h before the test; sleep normally before the test (about 8h); not conduct greater physical exertion than it is usual for the volunteer at least 1day before the test. According to volunteer’s answers to the participation and trial forms, all were non-smokers, didn’t drink tea, alcohol, eat spicy food, were right handed and had a usual physical exertion the day before the trial was conducted. Every day before the trial, it was recorded what they ate in their previous meal, what time they ate, if they took some medicines, the time when they went to sleep and when they woke up, as well the number of hours they slept. All subjects had the same working period of 8 hours, the morning part from 07:30 till 11:30, the pause of 1 hour, and finally the afternoon part from 12:30 till 16:30 (working hours varying depending on the process situation).

The experiments were conducted during a normal working day, with the subjects performing the usual tasks being exposed to SCE as usual and over the usual time period. Workers conducted usual industrial work of 8 hours at 16 to 18°C (measured at the height of 7 meters) and entered for several times in the frozen food chamber at air temperature of -25°C. Tskin was measured with Bioplux skin temperature sensors. The sensors were put on 8 measuring points (forehead, right scapula, left upper chest, right arm in upper location, left arm in lower location, left hand, right anterior thigh and left calf) according to ISO 9886:2004 (ISO 2004). For measuring the core temperature (Tcore) was used an Equivital ingestible pill sensor (thermometer telemetry capsule) with dimensions of 8.7 mm by diameter and 23 mm by length. It was swallowed with water for at least 5 hours before each test (usually before going to sleep); travelled along the digestive tract harmlessly, and leaving naturally within 24 to 72 hours. The sensors began to transmit one minute after the capsule activation by the external monitor, sending details every 15 seconds to the *EQ02 Life Monitor - Electronics Sensor Module* (SEM), which transmits the data via Bluetooth. The SEM is transported in a belt, recording the data from Tcore, chest skin temperature, heart rate and respiratory frequency.

2.3 *Clothing*

Clothes were given by the company as uniforms. The subjects normally wore normal cotton clothing (socks, underpants, t-shirt, trousers) and above it the cold protective clothing (jacket with a hood, trousers, boots), and sometimes gloves when entering the cold chamber.

2.4 *Data analysis*

The references were searched through databases by using the institutional IP address or University of Porto federate credentials. References were managed using the Mendeley 1.15.3. Tcore was recorded by using the Equivital Manager and EqView professional programs. Tskin was recorded by using the MonitorPlux program, later on to be processed by using the Matlab software program. The mean skin temperature was calculated using the weighting coefficients as suggested by ISO 9886:2004 (ISO 2004). Statistical analysis was done by using excel statistical toolbox.

3 RESULTS

As an example of Tskin and Tcore, results from two volunteers are illustrated in the figures 1, 2, 3 and 4, where 1 and 2 represent the data of one volunteer in the morning and afternoon, while 3 and 4 represent the data of the other worker. On the left side axis are illustrated values for the hand and mean skin temperature varying from 14 to 35°C, while on the right side axis are illustrated values for the core temperature varying from 37 to 38°C. The vertical lines represent the exposure to SCE, which is in accordance with radical dropping of hand temperature.

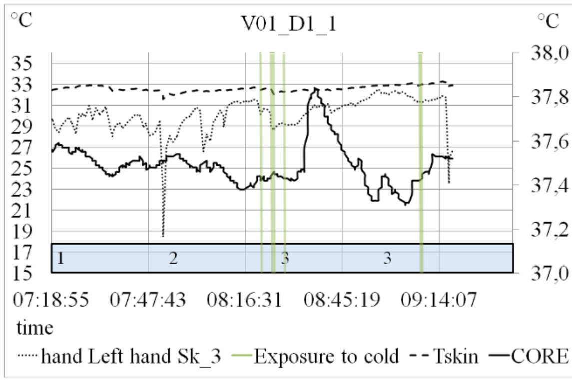

Figure 1. Results for the volunteer 1 on day 1 morning, left hand, Tcore and Tskin (1-working on a computer, 2-touching the cold package, 3-walking, counting, standing)

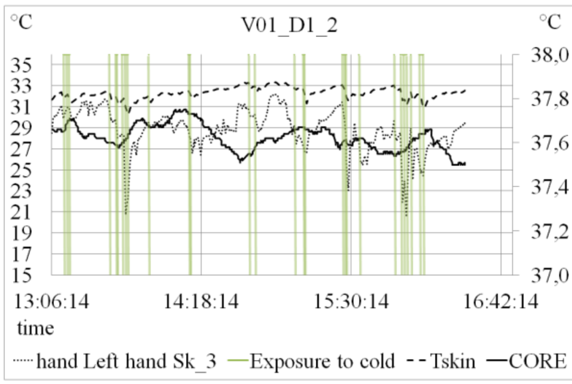

Figure 2. Results for the volunteer 1 on day 1 afternoon, left hand, Tcore and Tskin (logistic leader - delegate working tasks, control, supervise, count the packages)

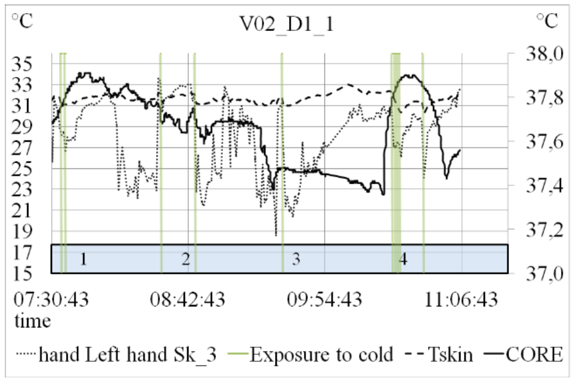

Figure 3. Results for the volunteer 2 on day 1 morning, left hand, Tcore and Tskin (1-packing packets (400g), 2-pushing 80kg, 3-pushing 100 kg packets, 4-hanging 20kg packet)

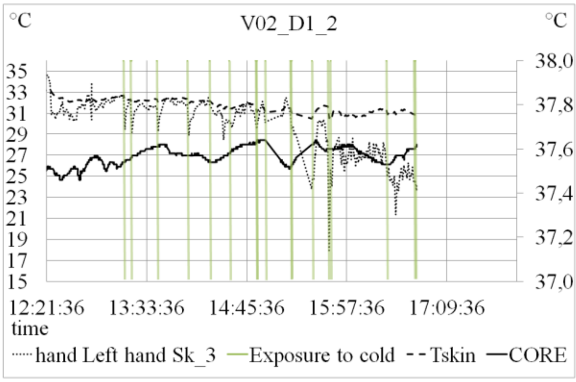

Figure 4. Results for the volunteer 2 on day 1 afternoon, left hand, Tcore and Tskin (loading packets with 20kg of shrimps, washing out, shaking, transfer to other package)

In table 2 are presented the mean, minimal (min) and maximal (max) values of two volunteers where the mean body temperature decreased below 35ºC.

Table 2. Minimal and maximal temperatures (ºC)

	Left hand	Forehead	Core Temp.	Mean skin Temp.	Mean body Temp.
Min	14.09	18.55	36.55	29.08	34.94
Max	34.64	35,41	37.91	34.29\	36.59

Temp. - temperature

4 DISCUSSION

The workers experienced big fluctuation in air temperatures along the working days between outdoor and indoor environments, which might result with AMI and stroke (Gill et al. 2013), therefore the workers should be controlled on regular basis and the risk should be managed and reduced [21.22].

In the figure 1, there is visible one radical dropping of hand temperature without the worker being exposed to SCE. In that case, the worker was touching the frozen food package in order to measure its temperature, but without using cold protecting gloves. The hand and forehead where found to have the highest and most frequent fluctuation in Tskin, which is reasonable as they were mostly not covered with the cold protective clothing. The forehead had a difference between the min and max recorded values, on average at least one time was recorded a drop of 5.32±3.64°C, with in one case dropping even to 18.55°C.

The hand had the biggest differences between the min and max recorded values, on average at least one time was recorded a drop of 10.43±4.87°C, with in one case dropping even to 14.09°C. The hand skin temperature recovery was fast, but when exposed to cold air or touching cold products or material it also dropped fast, making the changes of its temperature frequent, fast and with greater differences.

The mean Tskin show some small changes along the time, but without great and fast lowering or rising of the means Tskin, with a maximal variation between the min and max recorded value in one case of 5.14°C along all the measuring working period, and an average of between 1.10 to 3.20°C difference among the workers along all the measured working period.

The mean body temperature (Tbody) has no small change along the working period. As it is shown in the table 2, on two occasions: for V01_D3_1 and V02_D2_1, the mean Tbody drops slightly below 35°C (on the min measured values 34.98°C and 34.94°C respectively. The current literature has described it as the start of the mild form of hypothermia (general freezing) which occurs when the body temperature drops to 32-35°C, and appears with shivering, tachycardia, tachypnea and slowness of ideation and compensated dysarthria. On appearing of mentioned clinical features, the workers should start the rewarming process [22.24].

Tcore variations were always less then 1°C difference between the min and max value, in the most of the cases between 37 and 38°C. Tcore seems to be raising with the exposure to SCE, which could be explained with vasoconstriction (Charkoudian 2010). Nevertheless, the exposure to SCE was short and should be studied with larger time of exposure to SCE before making further conclusions. The type of movement with its speed (accelerometry) and physical exertion also seem to influence the raising of Tcore, and should be therefore furthermore studied in order to explain the Tcore variations during the working period.

5 LiMITATIONS

Challenges were found in transmitting the recorded data of the Bioplux skin temperature sensors. The equipment didn't have the possibility of recording the collected data directly to the device, but only by Bluetooth with a maximal distance of 10 meters from the equipment to the computer. As the workers were constantly moving it was challenging to stay constantly on a distance of less than 10 meters from the subject, following them when they entered the chamber and staying close to them while conducting the working activities. The number of subjects was limited to the number of workers present in the cold packing sector. One of the limitations was that activities carried out under SCE exposure varied from worker to worker. In the factory sector where the activities were developed the thermometer was located at 7 meters height and not at the height where workers worked, so there is no real information on to which environmental temperature the workers were exposed in the moderate cold sector.

6 CONCLUSIONS

Highest and most frequent fluctuations were found in the hand and forehead skin temperature. The mean Tskin showed some small changes along the time, but without great or rapid changes. The mean Tbody showed small fluctuations along the working period, but in two cases dropped slightly below 35°C which in the current literature has been described as the start of the mild form of hypothermia (general freezing). Tcore variations were always less then 1°C difference between the min and max value, in most of the cases between 37 and 38°C. It was concluded that Tcore was rising when exposed to SCE (because of vasoconstriction) and with higher physical exertion. Further experiments should be conducted with a higher number of volunteers, greater exposure to SCE, having a bigger sample with same working activities, thermal environment and time of exposure.

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Appendix 9 – Brazilian Portuguese version of IC, for industry

Programa Doutoral em Segurança e Saúde Ocupacionais

Declaração de Consentimento Informado

(Basado no Anexo A da ISO 12894:2001)

Nome……………………………………………………………Sexo : ❑ Masculino ❑ Feminino
Data de nascimento………………………………………....................
\Declaro para os devidos efeitos que:

1) Estou disposto a participar como voluntário, num estudo experimental, aceitado por o Comitê de Ética da Universidade do Porto, Portugal, subordinado ao tema: **" Influência do ambiente térmico extremamente frio no Desempenho de Tarefas ”**, a ser conduzido por uma equipa de investigação da Universidade do Porto, Universidade Federal de Pernambuco e a Universidade de Pernambuco no âmbito do Programa Doutoral em Segurança e Saúde Ocupacionais, em instalações da indústria **“Potiporã Aquacultura Ltda, Unidade de Beneficiamento”.**

2) Trabalho habitualmente em instalações frigoríficas e recebi uma explicação sobre a natureza e a finalidade deste estudo e de quaisquer riscos para a minha saúde que estão previstos e que podem ser:

a) A temperatura corporal (interna) pode baixar até aos 36ºC, limite fixado pela norma ISO9886

b) A temperatura corporal local da pele (face, mãos e pés) pode baixar até aos 15ºC, limite fixado pela norma ISO9886

c) Eventual dificuldade para deglutir a cápsula

d) Outro qualquer sintoma de stresse por frio que apareça durante o ensaio, como, por exemplo, dores de cabeça, náuseas ou vertigens, deve ser imediatamente comunicado e o ensaio suspenso.

3) Concordo em fornecer informações precisas sobre a minha saúde e ser submetido exame médico, se tal for necessário. Concordo que o meu médico de família forneça informações sobre o meu histórico médico para o médico independente autorizado para o estudo. Entendo que todas as informações sobre a minha saúde serão tratadas em sigilo.

4) Li os anexos 1, 2 e 3 referentes ao detalhe das atividades a desenvolver, às características das cápsulas e ao critério de exclusão de voluntários, respetivamente

5) Concordo em cooperar plenamente com os investigadores e não tomar qualquer atitude voluntária que possa invalidar os resultados.

6) Durante o curso das investigações, o qual estou dando o meu consentimento, comprometo-me a não participar, como voluntário, em qualquer outro estudo, sem informar previamente os investigadores e obter a sua aprovação.

7) Eu sei que sou livre para retirar o meu consentimento de participação no estudo a qualquer momento, sem necessidade de dar uma explicação para a minha decisão.

8) Autorizo expressamente que os dados obtidos na minha pessoa sejam utilizados para a produção de artigos técnicos e científicos, sendo garantido sigilo sobre a minha identidade.

Assinatura .... Data ....

Researcher declaration

Within the study described above, the research team has explained the comprehensive detail and purposes of the study and possible risks of the participation. Nevertheless the decision of the volunteer is not involved with the right of compensation in case of illness or injury, which might have been occurred during or after the data collection.

Signature .... (Tomi Zlatar) Date ....

Appendix 10 – Brazilian Portuguese version of the Information for the volunteer, for industry

Programa Doutoral em Segurança e Saúde Ocupacionais

Informações para o voluntário

Caro voluntário,

Uma vez mais, obrigado pela sua disposição para participar na pesquisa científica sobre o tema **"Influência do ambiente térmico extremamente frio no Desempenho de Tarefas"**. Eu acredito que isso vai ser uma experiência interessante para você e que ela vai dar a você uma perspectiva geral sobre pesquisas científicas. A pesquisa científica foi aprovada pelo Comitê de Ética da Universidade do Porto e pela Comitê de Ética da Universidade de Pernambuco, e vai usar todos os equipamentos de alta qualidade disponíveis para esta pesquisa cientifica.

- Sua participação pode ser dividida em duas fases:
  1. Controle médico (como é importante para o objetivo desta pesquisa ter indivíduos saudáveis, é necessário realizar um exame rápido na história da vossa doença e dificuldades cardiovasculares; mais adiante, vamos medir a sua altura e dar-lhe mais informações sobre a pesquisa)
  2. Você vai fazer as mesmas atividades de trabalho e no mesmo ambiente como outros dias, só que durante a pesquisa vamos medir alguns parâmetros. O ensaio será realizado durante dois dias consecutivos de trabalho.

- Equipamentos a serem utilizados:
  1. Sensores de temperatura da pele
  2. Comprimido ingestivel para medir a temperatura corporal interna e freqüência cardíaca
  3. Pressão do Sangue
  4. Contração voluntária máxima (fadiga muscular)
  5. Os questionários

- <u>Importante/ você deve:</u>
  1. Informar ao pesquisador se você é um fumante
  2. Não beber álcool por pelo menos 12 horas antes do ensaio
  3. Não beber café ou chá por pelo menos 12 horas antes do ensaio
  4. Não comer comidas picantes por pelo menos 12 horas antes do ensaio
  5. Não tomar qualquer medicação por pelo menos 12 horas antes do ensaio
  7. Dormir normalmente antes do teste (geralmente cerca de 8 horas)
  8. Não conduzir maior esforço físico do que é habitual para você, por pelo menos um dia antes do teste

Se alguma das seguintes situações foi violada, por favor informe sobre isso ao pesquisador.

Para qualquer informação adicional, não hesite em contactar-me a qualquer momento, tomi.zlatar@gmail.com ou +081/9 9644 3954.

Tomi Zlatar

Appendix 11 –Brazilian Portuguese version of the Cold Work Health Questionnaire, for industry

Programa Doutoral em Segurança e Saúde Ocupacionais

Questionário de saúde para trabalho a frio

(Baseado no Anexo D da ISO 15743:2008)

Nome…………………………………………………………………………………………………......................
Identificação do voluntário ...……………………………………………………………………….......................
Outro ...…………………………………………………………………...

De acordo com a tabela abaixo, por favor indicar na escala:

1. Como você geralmente se sentem no frio?

	Muito desagradável	Desagradável	Um pouco desagradável	Agradável
a) Todo o corpo				
b) Dedos				
c) Dedos do pé				

2. Está você excepcionalmente sensível ao frio?

a) Não	
b) Sim	

3. Você experimentou um intenso prurido da pele no frio ou após a exposição ao frio, relacionado a uma inflamação superficial ou como uma erupção cutânea?

a) Não	
b) Sim	

4. Você experimentou?

	Em frio	Em quente	No frio durante o esforço	de modo nenhum
a) Falta respiratoria				
b) Tosse prolongada ou ataques de tosse				
c) Poeira				
d) O aumento da excreção de muco dos pulmões				
e) Muito profundo rinite				

5. Você sente...?

	No quente	No frio	No frio durante o esforço	De modo nenhum
a) Dor do peito?				
b) Arritmias cardíacas?				
c) Pressão alta?				

6. Você sente episódios...?

	No quente	No frio	De modo nenhum
a) Distúrbios circulatórios nas mãos e / ou pés			
b) Embaçamento da visão			
c) Dor de cabeça (enxaqueca)			

7. Seus dedos são excepcionalmente sensíveis ao frio?

a) Não	
b) Sim	

8. A cor dos seus dedos está episodicamente mudando para ...

	No quente	No frio
a) Branco		
b) Azul		
c) Vermelho/violeta		

9. Você sente...

	No quente	No frio
a) Pescoço / ombro ou dor na extremidade superior		
b) Dor nas costas ou no quadril		
c) Dor nas extremidades inferiores		

10. Se você têve outro sintoma (por exemplo, tonturas, fadiga excepcional, dismenorréia, transitória paralisia dos membros, perda de memória transitória), em que condições você experimentou-o?

	No quente	No frio
a) Qual sintoma		
b) Qual sintoma		
c) Qual sintoma		

11. Você já teve congelamento do grau blister ou mais grave?

	No quente
a) Não	
b) Uma vez	
c) Várias vezes	

12. Como o frio afeta os seguintes fatores de seu desempenho durante o trabalho?

	Atuação diminuiu devido aos sintomas	Atuação diminuiu devido a refrigeração	Melhora desempenho	Sem efeito
a) Concentração				
b) Motivação				
c) Resistência músculo esquelética				
d) Outro – qual?				
e) Outro – qual?				

Appendix 12 – Brazilian Portuguese version of the Participation and trial form, for industry

Programa Doutoral em Segurança e Saúde Ocupacionais
Formulário sobre a participação e ensaios

Participation Code			
Informações do Voluntário (dados pessoais)			
Nome Completo:		Já passou pela avaliação médica:	SIM / NÃO
Sexo:	Masculino	Leu e assinou o consentimento informado:	SIM / NÃO
Data de nascimento (YY/MM/DD)		Que mão você usa com mais frequência?	
E-mail (não-obrigatório)			
Número do celular (não obrigatorio)			
Profissão:			

Trial Code		
Core Pill ID Code		
Date of the experiment		
Você é fumante?		SIM / NAO
Você bebeu álcool nas últimas 12 horas?		SIM / NAO
Você bebeu café nas últimas 12 horas? (quantidade usual)		SIM / NAO
Você bebeu chá nas últimas 12 horas? (quantidade usual)		SIM / NAO
Você comeu alimentos picantes nas últimas 12 horas?		SIM / NAO
Quando você comeu a sua última refeição hoje (quantas horas atrás)?		
O que você comeu na sua última refeição de hoje?		
Está você tomando algum medicamento? Qual?		SIM / NAO
Quando você foi dormir e quando você acordou?		
Número de horas de sono		
Você realizou qualquer tipo de esforço físico ontem? Se sim, como você classifica:		
MENOS QUE O HABITUAL	HABITUAL	MAIS DO QUE O HABITUAL

Depois do almoço...

Você bebeu álcool nas últimas 12 horas?	SIM / NAO
Você bebeu café nas últimas 12 horas? (quantidade usual)	SIM / NAO
Você bebeu chá nas últimas 12 horas? (quantidade usual)	SIM / NAO
Você comeu alimentos picantes nas últimas 12 horas?	SIM / NAO
Quando você comeu a sua última refeição hoje (quantas horas atrás)?	
O que você comeu na sua última refeição de hoje?	
Está você tomando algum medicamento? Qual?	SIM / NAO

Appendix 13 – Brazilian Portuguese version of the Thermal Sensation Questionnaire, for industry

Programa Doutoral em Segurança e Saúde Ocupacionais

Questionário Sensação térmica
(Basado no Anexo B da ISO 10551:1995)

Nome…………………………………………………………………………………………………...................
Identificação do voluntário ...……………………………………………………………………..................
Outro ...………………………………………………………………………...
Sexo: Feminino / Masculino

Roupa: Bota térmica Calça térmica (azul) Japona (azul)
Toca térmica Capu Luva térmica (azul)

DIA:________HORA:_________
TEMPERATURA: ____________

De acordo com a tabela abaixo, por favor indicar na escala de sensação térmica com um „X“
Neste exato momento como você se sente?

Muito Frio	Frio	Fresco	Ligeiramente Fresco	Neutro	Ligeiramente Morno	Morno	Quente	Muito Qunte
-4	-3	-2	-1	0	+1	+2	+3	+4

Como você percebe isso?

Totalmente Inconfortável	Muito Inconfortável	Incomfortável	Um pouquinho Inconfortável	Comfortável
-4	-3	-2	-1	0

Neste exato momento como gostaria de estar se sentindo?

Muito Mais Frio	Mais Frio	Um Pouquinho Mais Frio	Neutro (sem diferença)	Um Pouquinho Mais Quente	Mais Quente	Muito Mais Quente
-3	-2	-1	0	+1	+2	+3

Tendo em conta a sua preferência pessoal, você aceitaria trabalhar neste ambiente climático:

Sim	Não

É este ambiente, em sua opinião...?

Insuportável	Muito difícil de suportar	Bastante difícil de suportar	Um pouco difícil de suportar	Totalmente suportável
-4	-3	-2	-1	+1

Sentiu algum dos sintomas abaixo mencionados durante este período?

Sonolência	Enjoo	Vômitos	Tonturas	Calafrios	Ansiedade	Cansaço	Perda de coordenação motora	Nenhum

Appendix 14 – Detailed protocol, for industry

DETAILED PROTOCOL

Participation Code	
Trial Code	

POTIPORA AQUACULTURA LTDa, Pendencias, Rio Grande do Norte, Brazil
Title: Influence of Severe Cold Thermal Environment on Task Performance

There are several phases of this detailed protocol:
A) Medical control day
B) One day before the experimental day
C) On experimental day
1) Before the volunteer arrives
2) When the volunteer arrives
2.1.comfort
2.2. cold
2.3. .....
3) After the experiment is finished

A) Medical control day:

1.	Meet with the volunteer and go to conduct the medical control
2.	Get the feedback from the medical doctor on the physical condition of the volunteers

B) One day before the experimental day:

1.	Meet with the volunteer and schedule to meet the next day at 06:30 at the “Sala de Treinamento” totally prepared with clothes as if he would start to work
2.	Explain the purpose, equipment, protocol, and give to the volunteer the instruction flyer (which kind of food or drinks not to consume and other important information)
3.	Give the volunteer to read and sign the informed consent
4.	Give the core body temperature pill to the volunteer and explain how and when to take the pill, tell the volunteer not to open the package with the pill before they take it
5.	Prepare a working table and a chair in the working chamber, check for charging the laptop

C) On experimental day:
1) Before the volunteer arrives:

1.	Be at the industry at least at 06:00 am (30 minutes before the volunteer is scheduled)	
2.	Turn on the computer and all the programs needed for the experiment:	
	EQ02 Life Monitor (core body temperature)	
	Monitor Plux (skin body temperature)	
3.	Check and put in order all the equipment:	
	Skin temperature sensors (Sensors tempPlux - 8)	
	Skin temperature sensors (Monitor Bio Plux)	
	Alcohol bottle (for cleaning)	
	Patch of cotton (for cleaning)	
	Adhesive tape (for sensors)	
	Gear shift (Ativador Equivital, Hidalgo)	
	Belt (Colete Equivital) – adequate size for the volunteer	
	Device for core temperature (LifeMonitor, Equivital)	
	Scissors	
	Check the weighting scale	
4.	Check all printed materials:	
	Participation and Trials form	
	Thermal sensation questionnaire	
	Cold work health questionnaire	
	The photo for putting skin sensors (ISO 9886:2004)	
	Fulfil the known data into the Participation and Trial form	

2) When the volunteer arrives:

Phase 1

1.	Meet the volunteer in the “Sala de Treinamento”
2.	Check if the core temperature pill is functioning
3.	Question the volunteer and fulfill the Participation and trials form
4.	Measure and register the height of the volunteer. The volunteer should climb the scale platform, with the back facing the researcher. The volunteers back, head, buttocks, legs and heels should be touching the ruler of height scale. (only the first time the voluntary attend this type of experiment)
	HEIGHT = cm
5.	Measure and register the weight of the volunteer. The volunteer should wear underwear, afterward to climb the scale platform by facing the weight scale and the researcher
	WEIGHT = kg
6.	Explain to the volunteer to report if he feel dizziness or not feeling good
8.	Put 8 skin temperature sensors according to ISO 9886 (tape better the leg and the arm)
10.	Put the core belt
11.	Put the t-shirt
14.	Help the volunteer to dress the comfort OR cold protective clothes and shoes being careful not to flexion the wires of the skin and heart sensors
15.	Thermal sensation questionnaire
	Dress myself
	Take the laptop, camera, a pen and a paper, take the thermal sensation and cold work questionnaires
18.	Go with the volunteer to the working position at least 15 minutes before the process should start

Phase 2

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; COLD CHAMBER temp: _____ ; COLD CHAMBER Rh: _____
	3.	Control measuring parameters and abort the experiment if: - the subject feel any symptoms such as dizziness, nausea and general malaise - the core temperature go lower than 36.0ºC (ISO 9886) - the local skin temperature go lower than 15.0ºC (ISO 9886) (in particular for the extremities: face, fingers and toes)
	4.	Take photos of the volunteer working
	5.	Assure the signal for bioplux is constantly good and check the core pill information
	6.	Follow the volunteer with the laptop if he goes too far from the laptop

Phase 3

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

___ °C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____

	3.	Take photos of the volunteer working

°C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working
	3.	Take photos of the volunteer working

°C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

°C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

°C	1.	Note the time the volunteer entered the chamber
	2.	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER temp: _____ ; CHAMBER Rh: _____
	3.	Take photos of the volunteer working

Last phase

1.	Note the time the volunteer exit the climatic chamber
	TIME: _____ ; CORE TEMP: _____ ; RH: _____ ; CHAMBER TEMP: _____ ; CHAMBER RH: _____ ;
3.	Thermal sensation questionnaire
7.	Save data skin plux
8.	Save data core pills
11.	Remove the t-shirt, belt core, sensors
12.	The volunteer can take a shower / NOT DRINK WATER!
13.	Measure and register the weight of the volunteer. The volunteer should wear underwear, afterward to climb the scale platform by facing the weight scale and the researcher
	WEIGHT = kg
14.	Cold work health questionnaire / JUST FOR COLD EXPERIMENT
15.	Subjectively assessed age-related stress and strain associated with working in the cold questionnaire / JUST FOR COLD EXPERIMENT
16.	Thank the volunteer for the contribution
17.	Give to the volunteer another core body temperature pill for the next day and remind the volunteer not to drink coffee, tea or alcohol, and not to eat spicy food

C3) After the experiment is finished:

1.	Check if the data were stored according to the following checklist:	
	Core temperature records	
	Skin temperature	
	Anthropometric data	
	Thermal sensation questionnaire	
	Cold work health questionnaire	
2.	Put all data in the same folder at the UP account and on the USB stick	
3.	Clean all the equipment with alcohol and put all equipment at its place	
4.	Put to charge plux	

Appendix 15 – English version of the IC, for laboratory

U. PORTO

Doctoral Program on Occupational Safety and Health

Declaration of Informed Consent

(Base on Annex A of ISO 12894:2001)

Name…………………………………………………………………………………………………...
Gender : ❑ Male ❑ Female
Date of birth ………………………………………………………………………………………...

The declaration of all intents and purposes:

1) I am willing to participate as volunteer in this experimental study on the topic:
"Influence of cold thermal environment on human performance and fatigue", conducted by the research team of the Faculty of Engineering (FEUP), University of Porto, under the Doctoral Program of Occupational Safety and Health (DemSSO).

2) I have received an explanation of the comprehensive details and purposes of this study and any risks to my health:
a) the core body temperature can get lower to 36ºC, limit defined by ISO9886
b) the local skin temperature (face, fingers and toes) can get lower to 15ºC, limit defined by ISO9886
c) Possible difficulty swallowing the capsule
d) Other symptoms resulted from the cold stress, such as dizziness, nausea and general malaise;

3) I agree to provide accurate information about my health and ongoing medical examination if this is necessary. I agree to allow my personal doctor to provide information about my historical medical treatment to the authorized doctor of this study. I understand that all information about my health will be attentively treated in confidence.

4) I read the Annexes 1, 2 and 3 with details on activities, characteristics of the capsules and the voluntary exclusion criteria, respectively

5) I agree to fully cooperate with investigators and promise not to take any voluntary action that may invalidate the results.

6) During the period of investigations that I am now giving my consent, I promise not to participate as volunteer in any other study, without previously informed to the researchers of this research project and having obtained its approval afterward.

7) I know I am free to withdraw my consent of participation in the study at any time, without the necessity of giving an explanation for my decision.

8) I allow all data obtained from my body to be used for the production of research articles and I know that my identity will be kept secret at any processes.

Signature .... Date ....

Researcher declaration

Within the study described above, the research team has explained the comprehensive detail and purposes of the study and possible risks of the participation. Nevertheless the decision of the volunteer is not involved with the right of compensation in case of illness or injury, which might have been occurred during or after the data collection.

Tomi Zlatar

Signature .... Date ....

Appendix 16 – Portuguese version of the IC, for laboratory

U. PORTO

Doctoral Program on Occupational Safety and Health

Declaration of Informed Consent

(Base on Annex A of ISO 12894:2001)

Nome…………………………………………………………………………………………………...
Sexo : ❑ Masculino ❑ Feminino
Data de nascimento……………………………………………………………………………...

Declaro para os devidos efeitos que:

1) Estou disposto a participar como voluntário, num estudo experimental subordinado ao tema: **"Influência do ambiente térmico frio na performance e fadiga humana”**, a ser conduzido por uma equipa de investigação na Faculdade de Engenharia (FEUP), Universidade do Porto, do Programa Doutoral em Segurança e Saude Ocupacionais (DemSSO).

2) Trabalho habitualmente em instalações frigoríficas e recebi uma explicação sobre a natureza e a finalidade deste estudo e de quaisquer riscos para a minha saúde que estão previstos e que podem ser:
a) A temperatura corporal (interna) pode baixar até aos 36ºC, limite fixado pelo ISO9886
b) A temperatura corporal local da pele (face, mãos e pés) pode baixar até aos 15ºC, limite fixado pelo ISO9886
c) Eventual dificuldade para deglutir a cápsula
d) Outro qualquer sintoma de stresse por frio que apareça durante o ensaio, como, por exemplo, dores de cabeça, náuseas ou vertigens, deve ser imediatamente comunicado e o ensaio suspenso.

3) Concordo em fornecer informações precisas sobre a minha saúde e ser submetido exame médico, se tal for necessário. Concordo que o meu médico de família forneça informações sobre o meu histórico médico para o médico independente autorizado para o estudo. Entendo que todas as informações sobre a minha saúde serão tratadas em sigilo.

4) Li os anexos 1, 2 e 3 referentes ao detalhe das atividades a desenvolver, às características das cápsulas e ao critério de exclusão de voluntários, respetivamente

5) Concordo em cooperar plenamente com os investigadores e não tomar qualquer atitude voluntária que possa invalidar os resultados.

6) Durante o curso das investigações a que estou agora a dar o meu consentimento, comprometo-me a não participar, como voluntário, em qualquer outro estudo, sem informar previamente os investigadores e obter a sua aprovação.

7) Eu sei que sou livre para retirar o meu consentimento de participação no estudo a qualquer momento, sem necessidade de dar uma explicação para a minha decisão.

8) Autorizo expressamente que os dados obtidos na minha pessoa sejam utilizados para a produção de artigos técnicos e científicos, sendo garantido sigilo sobre a minha identidade.

Signature .... Date ....

Researcher declaration

Within the study described above, the research team has explained the comprehensive detail and purposes of the study and possible risks of the participation. Nevertheless the decision of the volunteer is not involved with the right of compensation in case of illness or injury, which might have been occurred during or after the data collection.
Tomi Zlatar

Signature .... Date ....

Appendix 17 – Information for the volunteer, for laboratory

U.PORTO

Trial information for the volunteer

Dear volunteer,

Once more, thank you for your time and willingness to participate in the scientific research on the theme **"Influence of Cold Thermal Environment on Human Fatigue and Performance"**. I believe this will be an interesting experience for you and that it will give you a general perspective on scientific researches. The scientific research has been approved by the Ethical Committee of the University of Porto and will use all top quality equipment available at the Faculty of Engineering of the University of Porto.

- <u>Your participation could be divided into two phases:</u>

1. Medical control (As it is important for the objective of this research to have healthy individuals, it is necessary to conduct a quick examination on illness history and some cardiovascular difficulties that you as a volunteer might have; further on, we will measure your height and give you further information on the research)
2. (09:15 – 12:30)
   Half an hour to one hour before the trial starts (for putting the equipment)
   One hour conducting different tasks in the climatic chamber at the cold temperature (-20˚C)
   One hour and a half outside at comfort temperature around 23°C in order for the body to stabilize

- <u>Equipment to be used:</u>

1. Skin body temperature sensors
2. Ingestible pill for measuring core body temperature
3. Heart rate belt
4. Blood pressure
5. Questionnaires

- <u>Important/ you should:</u>

1. not be a cigarette smoker
2. not drink alcohol for at least 12h before the test
3. not drink coffee or tea for at least 12h before the test
4. not eat spicy food for at least 12h before the test
5. **NOT EAT OR DRINK 2h BEFORE THE TEST**
6. not taken any medication at least for 12h before the test
7. slept normally before the test (usually about 8h)
8. not conducted greater physical exertion than it is usual for you at least 1day before the test
9. **DRINK THE CORE BODY PILL 12h BEFORE THE TEST (usually before you go to sleep)**

If any of the following was violated, please inform me in order to see if you can still participate.

- **<u>What to wear/bring to the test:</u>**

1. socks, underpants, undershirt, long trousers, long-sleeved shirt, sweater

Cold protective equipment (jacket, trousers, hood, gloves and boots) will be provided at the trial. If you wish to shower after the trial, a towel will be provided for you.

All the trials will be conducted at the Research Laboratory on Prevention of Occupational and Environmental Risks (PROA/LABIOMEP), Faculty of Engineering, University of Porto (FEUP). We will meet at the main entrance of FEUP at 09:15 on the scheduled day.

For any further information, feel free to contact me at any time at tomi.zlatar@gmail.com or +351/93 051 5599.

Tomi Zlatar, Ph.D. candidate

....

Appendix 18 – TSQ, for laboratory

U.PORTO

Doctoral Program on Occupational Safety and Health

Thermal sensation questionnaire

(Basado no Anexo B da ISO 10551:1995)

Put a mark „X“ in the boxes which represent your current sensation:

1. How do you feel at this precise moment: I am...

Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot
-4	-3	-2	-1	0	+1	+2	+3	+4

2. How do you find this?

Extremely uncomfortable	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Comfortable
-4	-3	-2	-1	0

3. At this moment, would you prefer to be?

Much cooler	Cooler	Slightly cooler	Neutral (without change)	Slightly warmer	Warmer	Much warmer
-3	-2	-1	0	+1	+2	+3

4. Taking into account your personal preference only, would you accept rather then reject this climatic environment:

Yes	No

5. Is this environment, in your opinion...?

Unbearable	Very difficult to bear	Fairly difficult to bear	Slightly difficult to bear	Perfectly bearable
-4	-3	-2	-1	0

6. Do you feel any of the following symptoms:

Sleepiness	Nausea	Vomiting	Dizziness	Anxiety	Tiredness	Apathy	Loss of motor coordination	Nothing
-4	-3	-2	-1	0	+1	+2	+3	+4

7. Do you feel pain in some parts of the body? Where?

8. Do you feel particularly cold in some parts of the body? Where?

Appendix 19 – Industry complementary data on CWHQ

In the figures 174-180 are illustrated complementary answers from all workers together to Cold Work Health Questionnaire (CWHQ):

Cold sensitivity

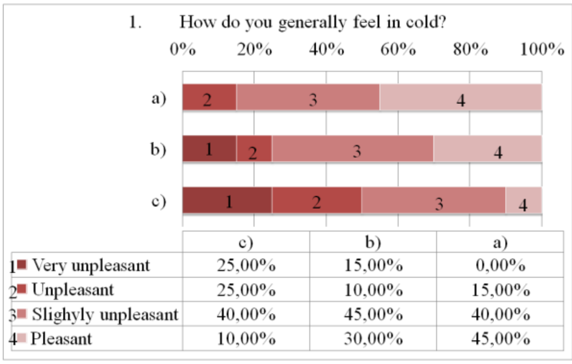

Figure 1 – Question 1: How do you generally feel in cold? a) Whole body, b) Fingers, c) Toes

Respiratory symptoms

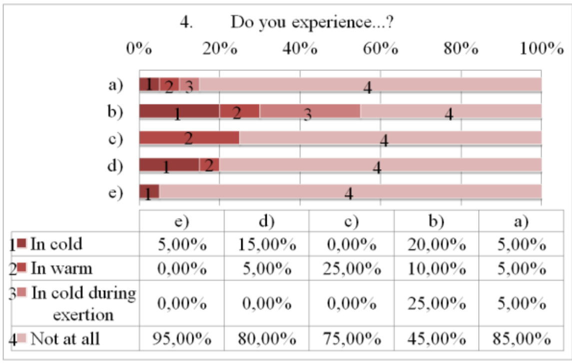

Figure 2 – Question 4: Do you experience...?
a)Shortness of breath?, b) Extended coughing or coughing fits?, c) Wheezing?, d) Increased excretion of mucus from the lungs?, e) Very profound rhinitis?

Cardiovascular symptoms

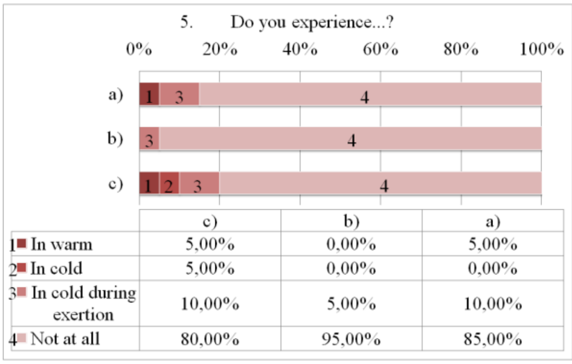

Figure 3 – Question 5: Do you experience...?
a) Chest pain?, b) Cardiac arrhythmias?, c) High blood pressure?

Symptoms related to peripheral circulatory disturbances

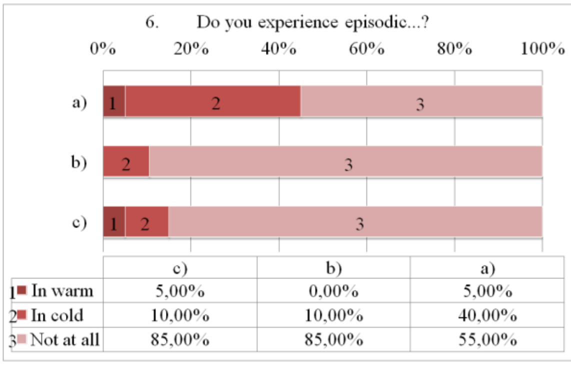

Figure 4 – Question 6: Do you experience episodic...? a) Circulatory disturbances in hands and/or feet, b) Blurring of vision, c) Headache named migraine

Symptoms related to white fingers

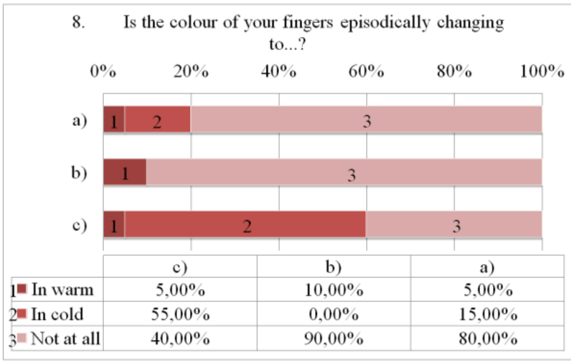

Figure 5 – Question 8: Is the colour of your fingers episodically changing to...?
a) White, b) Blue, c) Red/violet

Symptoms related to musculoskeletal system

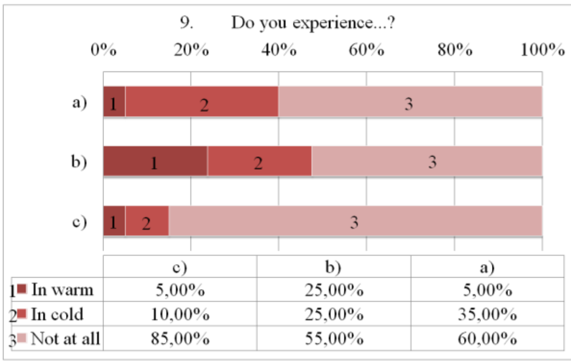

Figure 6 – Question 9: Do you experience...?

a) Neck/shoulder or upper extremity pain, b) Back or hip pain, c) Pain in lower extremities

Effects of cold on performance

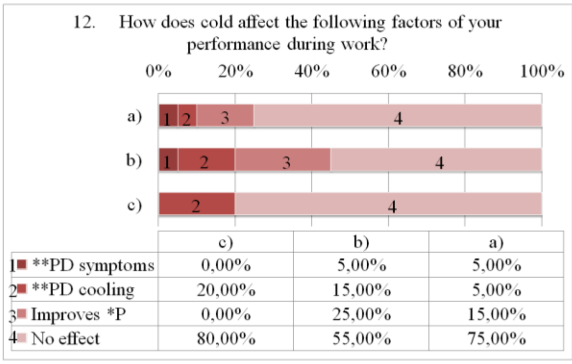

Figure 7 – Question 12: How does cold affect the following factors of your performance during work? a) Concentration, b) Motivation, c) Musculoskeletal endurance
*P = performance **PD = performance decreased due to

In the tables 15-19 are illustrated complementary answers from all workers together to Cold Work Health Questionnaire (CWHQ) questions 2, 3, 7, 10 and 11:

Table 1 – Question 2: Are you exceptionally sensitive to cold?

	Male	Female	Total
No	80.00%	90.00%	85.00%
Yes	20.00%	10.00%	15.00%

Table 2 – Question 3: Do you expeience an intense itching of the skin in the cold or after cold exposure, related to a superficial inflammation (eczema) or like a rash (urticaria)?

	Male	Female	Total
No	80.00%	100.00%	90.00%
Yes	20.00%	0.00%	10.00%

Table 3 – Question 7: Are your fingers exceptionally sensitive to cold?

	Male	Female	Total
No	30.00%	70.00%	50.00%
Yes	70.00%	30.00%	50.00%

Table 4 – Question 10: If you have another symtom (e.g. dizziness, exceptional fatigue, dysmenorrhea, transient paralysis of limbs, transient memory loss), under what conditions do you experience it?

a) What symptom ?	Male		Female		Total	
	In warm	In cold	In warm	In cold	In warm	In cold
transient paralysis of limbs	0.00 %	10.00 %	0.00 %	0.00 %	0.00 %	5.00 %

Table 5 – Question 11: Have you ever had frostbite of blister grade or more severe?

	Male	Female	Total
a) No	100.00%	100.00%	100.00%
b) Once	0.00%	0.00%	0.00%
c) Several times	0.00%	0.00%	0.00%

Appendix 20 – Industry complementary data on TSQ

In the tables 20-25 are illustrated complementary answers from all workers to the Thermal Sensation Questionnaire (TSQ):

Table 6 – How do you feel at this precise moment: I am...

	Very cold	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot	Very hot
	-4	-3	-2	-1	0	1	2	3	4
Start Morning	1	17	11	3	1	0	1	0	0
End Morning	3	4	1	3	1	0	1	0	0
Start Afternoon	1	10	6	1	3	1	2	0	1
End Afternoon	3	7	12	2	3	0	0	1	0

Table 7 – How do you find this?

	Extremely uncomfortable	Very uncomfortable	Uncomfortable	Slightly uncomfortable	Comfortable
	-4	-3	-2	-1	0
Start Morning	0	2	3	19	10
End Morning	1	0	1	9	2
Start Afternoon	0	0	2	7	16
End Afternoon	1	0	4	10	13

Table 8 – At this moment, would you prefer to be?

	Much cooler	Cooler	Slightly cooler	Neutral (without change)	Slightly warmer	Warmer	Much warmer
	-3	-2	-1	0	1	2	3
Start Morning	0	0	2	14	17	1	0
End Morning	0	0	1	0	8	3	1
Start Afternoon	0	2	6	6	9	2	0
End Afternoon	0	3	2	6	15	2	0

Table 9 – Taking into account your personal preference only, would you accept rather than reject this climatic environment:

Yes	No
99	1

Table 10 – Is this environment, in your opinion...?

	Unbearable	Very difficult to bear	Fairly difficult to bear	Slightly difficult to bear	Perfectly bearable
	-4	-3	-2	-1	0
Start Morning	1	0	0	17	16
End Morning	1	1	0	4	7
Start Afternoon	1	0	0	7	17
End Afternoon	0	0	0	12	16

Table 11 – Do you feel any of the following symptoms:

	Sleepiness	Nausea	Vomiting	Dizziness	Anxiety	Tiredness	Apathy	Loss of motor coordination
Start Morning	5			2	1	15		
End Morning	2					5		
Start Afternoon	3				1	9		
End Afternoon	4				1	13		

Appendix 21 – Laboratory complementary data on Acc and Tcore variations

The volunteer 4 Acc and core data were lost. The volunteer 6 was excluded from the data treatment as he was a cigarette smoker. In the figures 196-207 are illustrated complementary accelerometry and core temperature for laboratory volunteers (LV) 1-13.. Periods within the severe cold chamber are marked by vertical green shaded areas, while experimental protocol phases start/end are marked by vertical purple shaded lines. In the those figures, it is visible in most cases a decrease in Tcore upon exposure to SCE. The Tcore follows movement increase but with a delay, increasing throughout the exposure to SCE. After SCE exposure the accelerometry data show decrease in movement and Tcore follows.

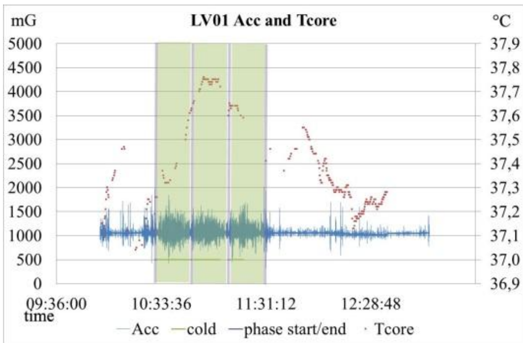

Figure 8 – Results for the laboratory volunteer 1, total accelerometry (Acc) and core temperature variations

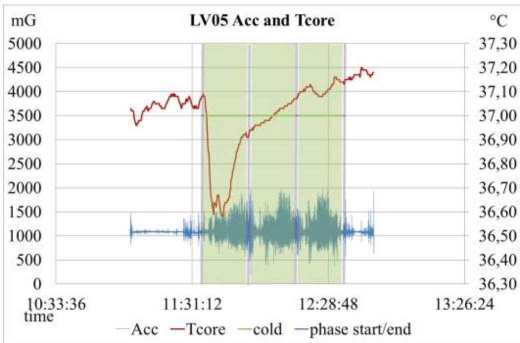

Figure 11 – Results for the laboratory volunteer 5, total accelerometry (Acc) and core temperature variations

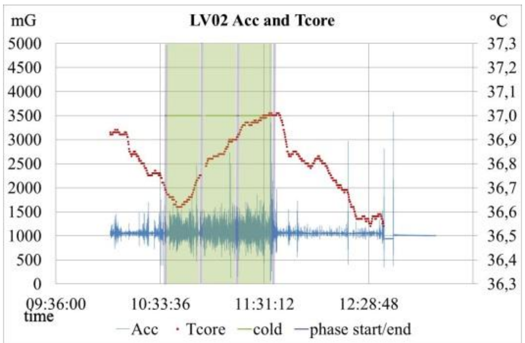

Figure 9 – Results for the laboratory volunteer 2, total accelerometry (Acc) and core temperature variations

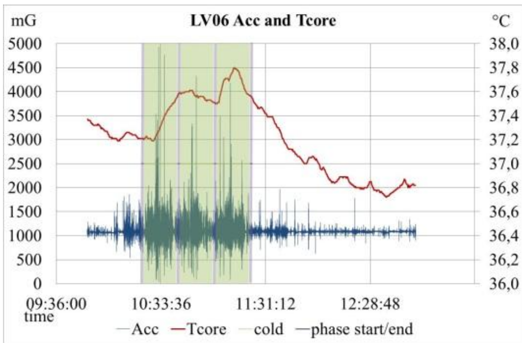

Figure 12 – Results for the laboratory volunteer 6, total accelerometry (Acc) and core temperature variations

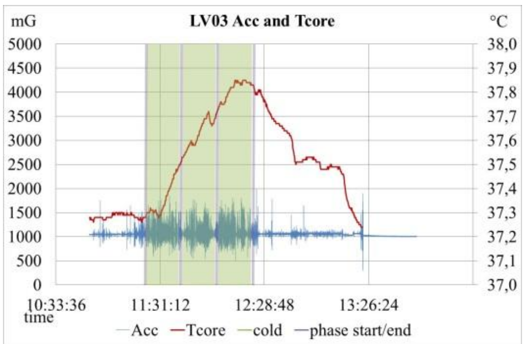

Figure 10 – Results for the laboratory volunteer 3, total accelerometry (Acc) and core temperature variations

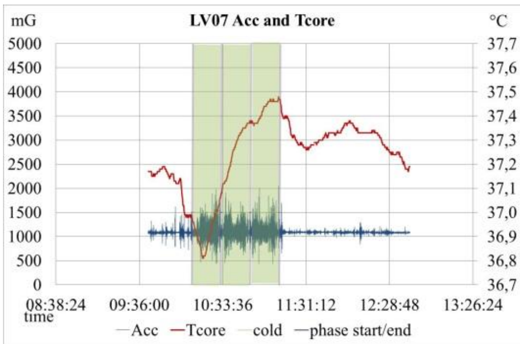

Figure 13– Results for the laboratory volunteer 7, total accelerometry (Acc) and core temperature variations

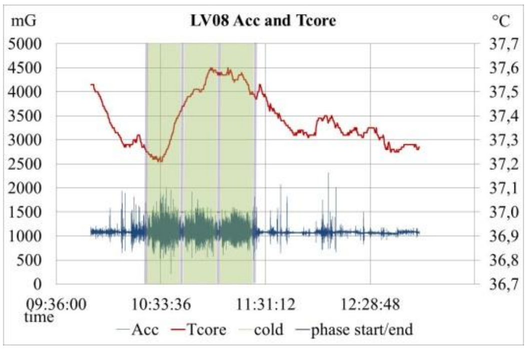

Figure 14 – Results for the laboratory volunteer 8, total accelerometry (Acc) and core temperature variations

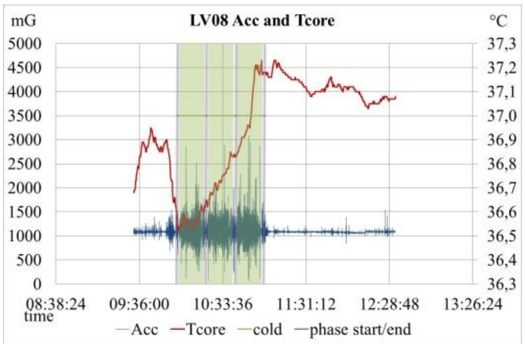

Figure 15 – Results for the laboratory volunteer 9, total accelerometry (Acc) and core temperature variations

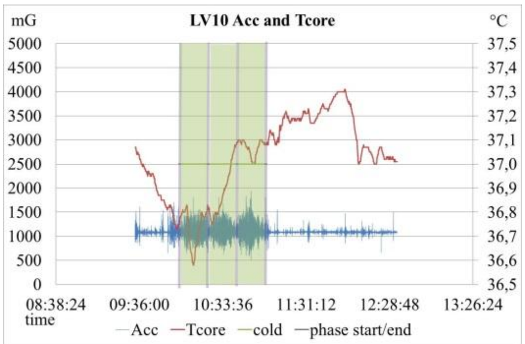

Figure 16 – Results for the laboratory volunteer 10, total accelerometry (Acc) and core temperature variations

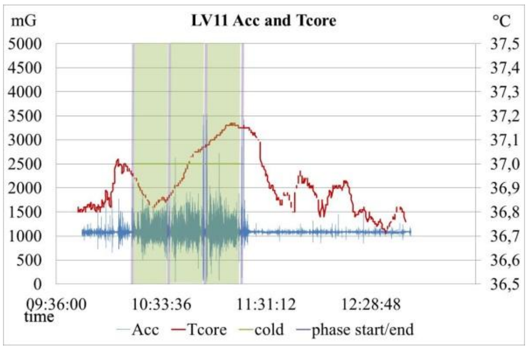

Figure 17 – Results for the laboratory volunteer 11, total accelerometry (Acc) and core temperature variations

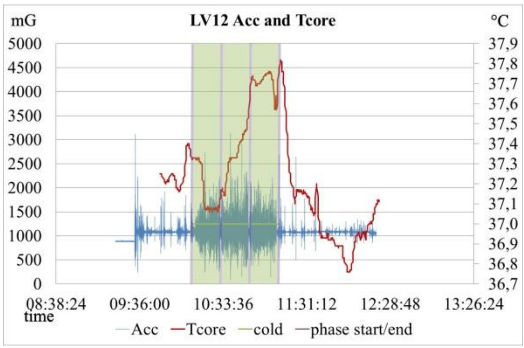

Figure 18 – Results for the laboratory volunteer 12, total accelerometry (Acc) and core temperature variations

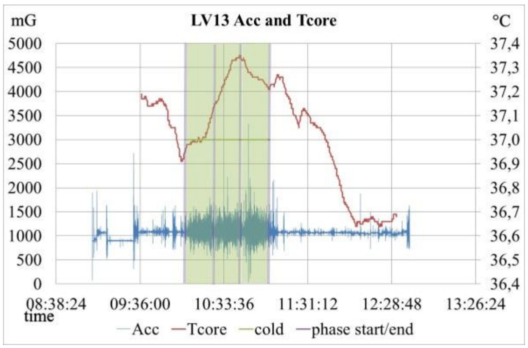

Figure 19 – Results for the laboratory volunteer 13, total accelerometry (Acc) and core temperature variations